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PALEOECOLOGY, STRUCTURE, AND DISTRIBUTION OF TRIASSIC CORAL BUILDUPS IN WESTERN NORTH AMERICA

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PALEOECOLOGY, STRUCTURE, AND DISTRIBUTION OF TRIASSIC CORAL BUILDUPS IN WESTERN NORTH AMERICA[1]

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ABSTRACT

Coral buildups are widely distributed in Middle and Upper Triassic rocks in Nevada, California, Oregon, Idaho, British Columbia, and Alaska. They developed in a wide variety of tectonic and depositional settings ranging from relatively stable carbonate platforms to active volcanic arcs during the Ladinian through Norian ages but were best represented during the Norian. Although many workers have referred to these features as reefs, their stratigraphic relationships, paleoecology, biologic structure, and petrography show that, unlike modern reefs, they are thin, lenticular, relatively small-scale carbonate accumulations that did not attain much relief above the sea floor. Many of the buildups possess organic framework, but some do not, and most lack evidence of formation in high-energy environments or the development of wave-resistance. Most buildups developed in shallow water but some are interpreted as having developed in deeper water.

The buildups are dominated by corals and spongiomorphs supplemented by calcisponges, brachiopods, mollusks, echinoids, and crinoids. In many buildups, the framework is produced by coelenterates, some of which display vertical zonation with respect to taxonomic composition and growth forms.

Coral diversity ranges from only a few species in some buildups to as many as 22 in others. Most noncoelenterate benthonic invertebrates form a distinct zoogeographic province within North America, but the corals are quite cosmopolitan and show consistently high levels of similarity with Tethyan faunas in Upper Triassic carbonate buildups of Germany, Austria, and Italy.

Based on the paleoecology and geographic distribution of the corals, including their occurrences at high latitudes and in deeper water deposits, it is concluded that many if not all of the Triassic corals were ahermatypic. During the Triassic, early scleractinians may have been acquiring a hermatypic association with algae, a condition that enabled subsequent rapid diversification and true reef-building.

INTRODUCTION

North American Triassic coral reefs or buildups have been reported in limestone intervals in mountain ranges of Nevada, northern California, northeastern Oregon, and in coastal ranges of British Columbia and Alaska. Most reports between 1911 and 1956 were short, preliminary notes lacking in details of "reef" shape and structure, but almost all coral buildups reported are of Late Triassic (Norian) age and are dominated by both scleractinian corals and spongiomorphs. The origin of scleractinian corals is still a subject of controversy (Ilina, 1971). Earliest known examples appear in the Middle Triassic, but these were not significant in the construction of large reefs or buildups until the Late Triassic (Fig. 1).

The developmental history of these corals has been derived mainly from studies in central and southern Europe, especially the Alpine sequences of Germany, Austria, and northern Italy. North American counterparts may hold important information about reef building among early scleractinians, but have been much less studied for two reasons. First, the exposure of marine Triassic rocks within the Cordilleran region is limited to structurally complex remnants, some in rugged and remote areas that have not been geologically investigated in detail. Second, knowledge of Triassic history in western North America has been hampered by an inadequate biostratigraphy. Only in the 1950's were correlation schemes satis-

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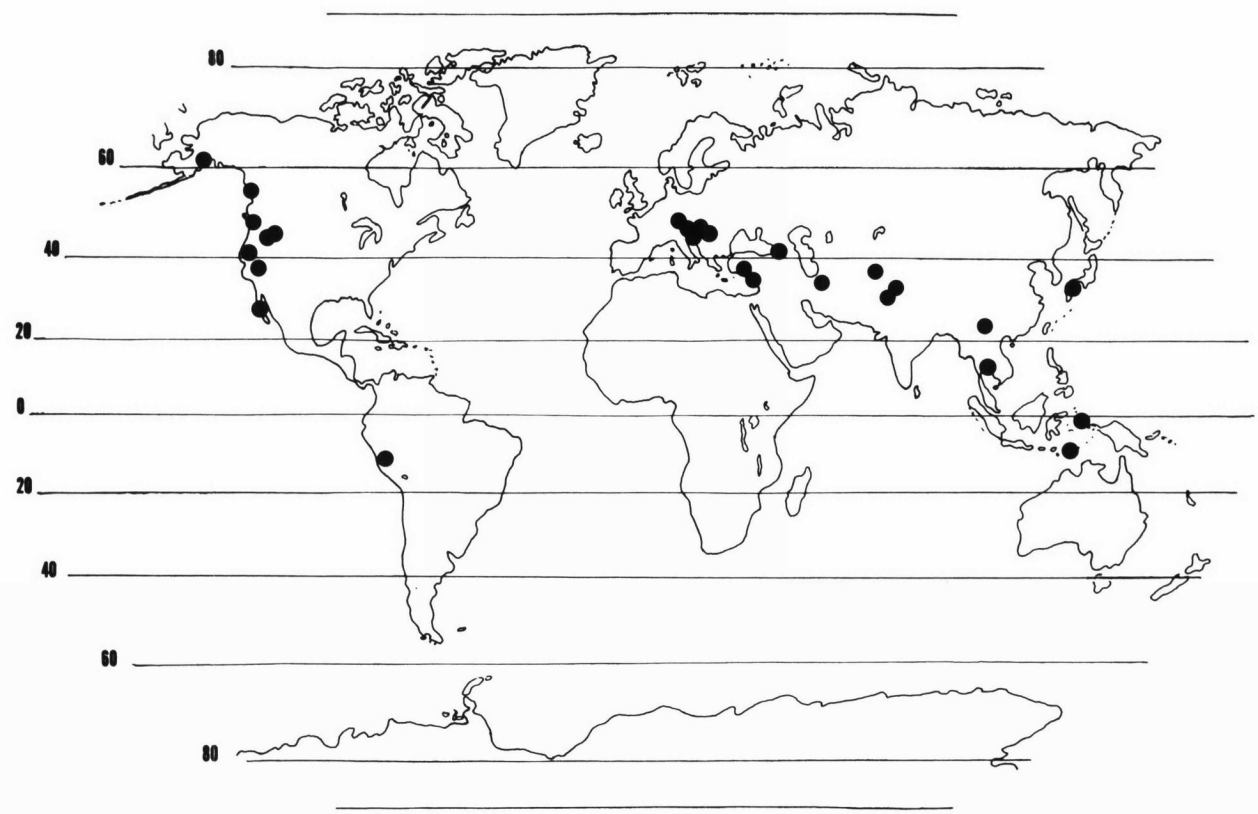

FIG. 1. World distribution of Upper Triassic coral faunas.

factorily applied to these geographically isolated outcrops (McLearn, 1953; Reeside *et al.*, 1957). Since then, studies by Tozer (1967) and Silberling and Tozer (1968) have produced a more refined biostratigraphy, permitting the Triassic coral buildups to be more accurately dated.

In his brief discussion of the presence and geographical significance of Triassic coral reefs in western North America, it is clear that Smith (1912) believed all occurrences to represent one great coral zone of interregional significance that, like the modern coral reef, indicated a warm, tropical marine environment. Including occurrences in Baja California (D. L. Jones, pers. commun., 1978) and South America (Körner, 1937), Triassic corals presently range in latitude from approximately 12° S. to 60° N. (Fig. 1) and produce a belt much broader than that of present-day tropical reefs.

Most authors have interpreted coral buildups to be features developed in shallow, tropical, marine environments (e.g., Schwarzbach, 1963, on Triassic reefs; Dott and Batten, 1976, p. 344); however, Teichert (1958) has discussed deep and cold-water coral banks that could easily be mistaken for shallow, tropical reefs if preserved in the rock record.

The Triassic buildups of North America are dominated by astrocoeniid, montlivaltiid, and thamnasteriid corals that differ little over wide latitudinal ranges and show pronounced affinities with the Triassic faunas of Europe. Although much work has been devoted to Tethyan faunas (Cuif, 1965, 1972-1976; Melnikova, 1967, 1971, 1972), those of North America have received only minor attention. Since the work of Smith (1927), the only detailed systematic treatment is that of Squires (1956). Part of the problem is that most North American corals have been subjected to varying degrees of recrystallization, usually obscuring vital details of the skeletal structure. In the present investigation, some coral faunas from Idaho and Vancouver Island have been found to be silicified and unusually well preserved.

The purpose of this study is to document the species composition, biotic structure, stratigraphy, paleoecology, and carbonate lithofacies of Triassic coral buildups in western North America and to analyze their regional significance. Also, comparison is made with other areas of the world known to contain coral buildups of similar age. A thorough systematic reevaluation of the Triassic corals of North America, including detailed comparison

with the large Alpine collections described by Frech (1890), Laube (1865) and others, is still needed. Sra. E. Gallitelli of Modena, Italy, has been engaged in a comparative study of Alpine and North American corals but I am unaware of the status of her work.

To facilitate identifications of the North American coral taxa, I have examined Smith's type material and have encountered many of the same taxonomic problems pointed out by Squires (1956). Even though some problems are evident in the taxonomy of the corals, the findings and the general validity of the conclusions reached herein are not materially affected.

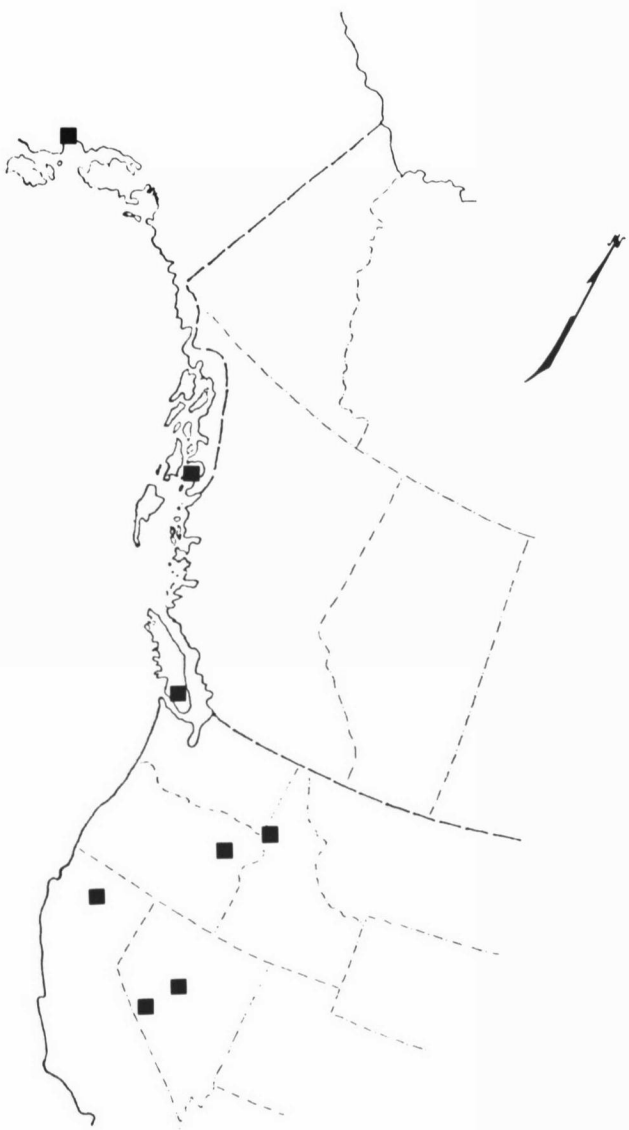

FIG. 2. Triassic coral localities in western North America. Squares indicate study areas described in text.

METHODS OF STUDY

Field work on the buildups was carried out between 1975 and 1977 in Alaska, British Columbia, Oregon, Idaho, California, and Nevada (Fig. 2) and involved 1) detailed description and quantitative documentation of the fossil biota with special emphasis on the corals and spongiomorphs, and 2) mapping, measuring, and sampling of the limestone. Laboratory work entailed the preparation and study of large polished and oriented slabs as well as thin sections and acetate peels to determine the biologic and lithologic composition of the limestone.

Petrographic analysis, using classifications by Folk (1962), Dunham (1962), and Embry and Klovan (1972), provided the basis for interpretations of depositional environment and biologic development of the buildups. The buildups are classified according to the scheme proposed by Heckel (1974), which is reproduced in Figure 3.

PREVIOUS WORK

Smith (1912) first discussed reefs of Late Triassic age in northern California, northeastern Oregon (Wallowa Mountains), southwestern Nevada, and at Lake Iliamna near Cook Inlet, south-central Alaska, comparing them briefly with the coral reefs of the Alps and Mediterranean areas. Smith concluded that these corals were lower Norian and all were equivalent in age, constituting a new and significant zone of much importance in correlation.

A Triassic locality on Vancouver Island, British Columbia, described a year earlier as a coral reef by Clapp and Shimer (1911), was omitted by Smith (1912). Clapp and Shimer described Late Triassic corals and associated mollusks that they erroneously thought to be Jurassic in age. The basis for a Triassic age was discussed by Fyles (1955).

Martin (1916) mentioned Triassic coral occurrences at Lake Iliamna, southern Alaska and on Gravina Island, along the southeastern panhandle of Alaska. He related both occurrences to the lower Norian coral zone of Smith (1912). He also discussed Triassic corals in the Nizina Limestone of the Chitina Valley area. Martin (1916, p. 710) suggested a Late Triassic (Norian) age for the corals on Vancouver Island but at the same time pointed out that some elements of the Vancouver Island fauna were distinct from the lower Norian reef zone of Smith.

Chapin (1918) presented the results of U.S. Geological Survey investigations on Gravina Island. He described abundant corals from a structurally complex sequence of Triassic limestone and shale along the southwest side of the island. In a correlation table, Chapin (1918, p. 86) indicated that the coral-bearing sequence of Gravina Island was equivalent to the limestone and volcanic succession on Vancouver Island and that both were part of Smith's lower Norian coral zone.

Following the initial report (Clapp and Shimer, 1911) on the coral reef near Lake Cowichan, Shimer (1926) described a second Triassic coral reef fauna from the Pine River area of Vancouver Island. This locality is 240 km NNE. of Lake Cowichan and the fauna is almost identical in composition with that from Lake Cowichan, indicating a Norian age.

Smith (1927), in a major monograph on Late Triassic marine faunas, summarized his views on the Triassic corals of North America, described and illustrated many of the relevant corals and spongiomorphs, and reiterated the existence of an interregional coral zone of early Norian age. He placed all known Triassic coral occurrences in this zone, to which he attributed a rank similar to zones based on ammonites. It seems clear from Smith's writings that he envisioned a generally persistent coral fauna, which during the early Norian had developed reef structures all along the border of western North America.

Throughout the discussion of the "coral reefs," Smith (1927) gave surprisingly little information concerning details of the limestones, never mentioning the criteria used to identify them as reefs. Smith (1927, p. 3) remarked that similarities between Tethyan and North American faunas indicated free migration between the reef faunas of North America and Europe, an idea he had promoted earlier (Smith, 1904). Using direct analogies with modern coral reefs, Smith (1927) inferred tropical climates for North America during the Triassic and cited broader climatic belts to explain the present-day distributional data.

Muller (1936a, b), in discussing Triassic coral reefs from Nevada, questioned the basis of Smith's postulated interregional coral zone. He cited even older "reef" horizons from the Middle Triassic of central Nevada. Based on ammonite and brachiopod occurrences, Muller (1936a) identified numerous coral-reef horizons in the Pilot Mountains, Nevada, as Karnian in age. He pointed out that ammonites were conspicuously absent within the horizons. Like Smith, Muller (1936a) said little about the nature of the reefoid bodies. In fact, no reference is made to the rock types in which the corals occur nor the thickness of the intervals in question.

In the same publication, Muller (1936a, p. 205) listed the corals from Nevada and compared them with those from other localities in North America and Europe. He concluded that from the Middle Triassic (Ladinian) through the Late Triassic (Karnian-Norian) there was little differentiation of corals between North America and Europe. Accordingly, he questioned the validity of an interregional biostratigraphic coral zone as proposed by Smith (1912, 1927). To emphasize his findings, Muller (1936c) published a new biostratigraphic chart that placed Smith's single coral zone in various horizons within the Ladinian, Karnian, and Norian stages.

Muller and Ferguson (1936, 1939) presented stratigraphic details of the rock types and facies relationships of coral horizons in the Pilot Mountains, Nevada, but important data on thickness, shapes, and biotic associations were still missing. The coral-bearing strata were still referred to as "coral reefs" and, in fact, on a geologic map published in 1954 by H. G. Ferguson *et al.* (Geo-

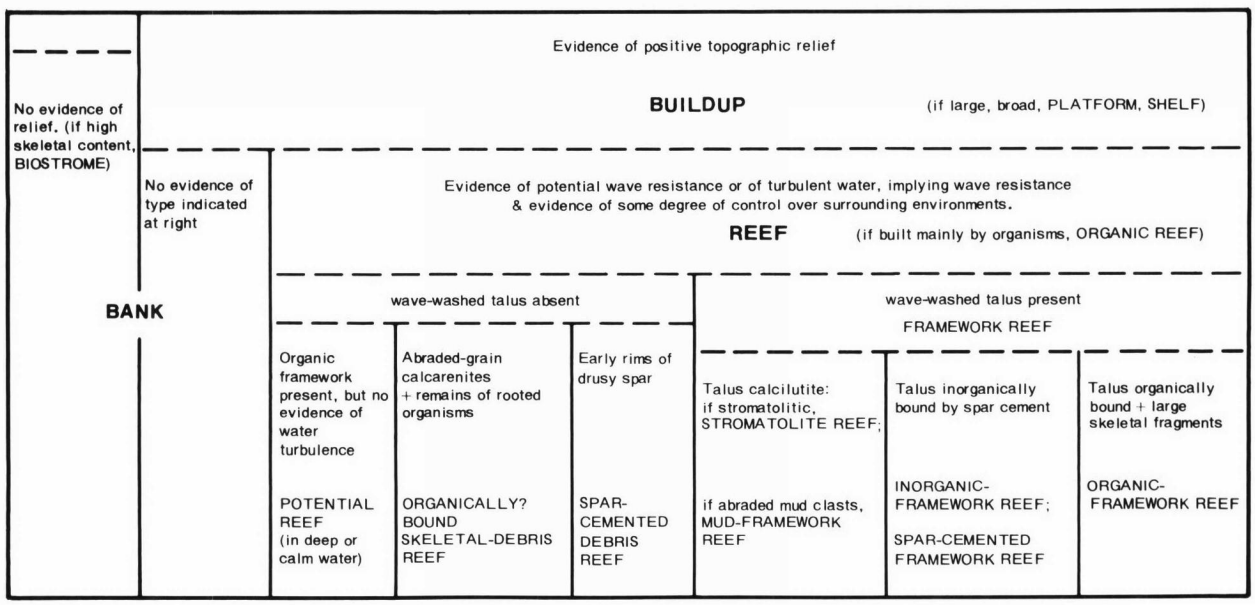

FIG. 3. Classification of reefs and buildups by Heckel (1974, p. 98). Terms are in upper case letters and criteria in lower case letters.

logic Map of the Mina Quadrangle, U.S. Geol. Survey 30 minute series, 1:125,000) the outcrop of coral reefs is shown throughout the area as a lithologic unit. Muller and Ferguson (1939) pointed out that mappable units referred to as "coral reefs" occur over a broad area in southwestern Nevada, persisting at the same stratigraphic interval throughout 110 km of outcrop. They interpreted the reefs to have developed in shallow seas just offshore from a land mass to the east that was intermittently shedding terrigenous sediments.

After the reports by Smith and Muller, no other information appeared until Squires' (1956) description of a new coral-reef fauna near Lewiston, Idaho. This exceedingly rich and well-preserved silicified fauna, containing many coral taxa previously known only from Europe, revealed even greater similarity between western North America and Europe. Squires also mentioned possible similarities between the Idaho fauna and those from Peru. On the basis of sponges, brachiopods, and mollusks, a Late Triassic age was established for the Idaho fauna. Squires (1956) suggested that the rich coral fauna probably represented a bank rather than a true reef but it is clear that, although he described the fauna, he never visited the locality.

With the refinement of the Triassic biostratigraphy by Tozer (1967) and Silberling and Tozer (1968), it seems appropriate to undertake a new analysis of the age, composition, and paleoecology of Triassic coral buildups in North America.

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TECTONIC-DEPOSITIONAL SETTING FOR MARINE TRIASSIC ROCKS IN NORTH AMERICA

Triassic coral buildups developed along the western margin of North America following a particularly active period of volcanism and tectonism. Because these buildups occur in a variety of rock types and are presently distributed over a broad area, an understanding of Triassic tectonic and depositional settings is important to interpretation of their ancient distribution, paleoecology, and climatic implication.

Unraveling the complex stratigraphic and tectonic history of the Mesozoic rocks of the Cordilleran region has been complicated by the fact that all of the rocks are intruded and deformed as a result of successive orogenesis during the Mesozoic and Cenozoic. Most Triassic rocks are now preserved as folded and frequently thrust-faulted remnants. In addition, outcrops are scattered and frequently isolated, posing major problems in stratigraphic interpretations and in correlation. Fortunately, refinement of the biostratigraphy has permitted more precise correlation of marine Triassic rocks in most isolated areas; however, the age of some thick intervals remains equivocal.

Triassic rocks in the Cordilleran region have traditionally been divided into a western eugeosynclinal and an eastern miogeosynclinal belt. Rocks in the eugeosyncline contain thick sequences of theoleiitic basalt, volcaniclastic deposits, thick intervals of shale and argillite, and relatively minor amounts of limestone. Many of the coral buildups occur in these thinner limestone intervals. To the east, in the miogeosyncline, contemporaneous Triassic rocks consist of typical nonvolcanic shelf deposits. Still further east, these merge into terrigenous clastics that were derived from an eastern source.

Major differences in rock types and sequence are apparent parallel as well as perpendicular to the structural strike. Obvious differences between rock sequences in close proximity caused such workers as Silberling (1971) to theorize that many of the marine Triassic rocks along the western margin of North America developed independently of the craton.

GEOLOGY OF SPECIFIC REGIONS

Perhaps the most complete marine Triassic record is present in central and western Nevada. According to Sil-

berling and Roberts (1962), Middle Triassic volcanism characterized the region following the Early Triassic Sonoman orogeny. After a period of Middle Triassic erosion, the sea moved eastward across Nevada and deposited a thick shelf sequence of shallow-water sedimentary rocks, which range from late Early to Late Triassic in age (Silberling, 1975; Silberling & Wallace, 1969).

In the Hawthorne and Tonopah quadrangles of Nevada, Upper Triassic sedimentary rocks were termed the "Luning Sequence" by Silberling and Roberts (1962). This includes strata ranging from the Karnian or upper Ladinian through the Jurassic. As pointed out by Muller and Ferguson (1939), sedimentation appears to have been continuous across the system boundary. The Luning Formation of western Nevada contains considerable amounts of limestone deposited during Karnian and Norian ages. According to Muller (1936a), the Luning contains numerous coral reefs. These developed in a broad northeast-trending seaway, the "Luning Embayment" (Ferguson and Muller, 1949). In this region, the lowest Jurassic rocks are folded and thrust faulted, which indicate renewed orogenic activity. Oldlow (1975) has reported a succession of allochthonous nappes in the Luning Formation that result in the juxtaposition of some carbonate facies. Displacements on the order of 20 km are indicated.

In the Klamath Mountains of northern California, important Middle to Upper Triassic rocks are characterized by thick shale and limestone. Ages are well documented by diagnostic fossils (Silberling and Tozer, 1968). In this region pure shallow-water limestone of Late Triassic age has been assigned to the Hosselkus Limestone, and coral reefs have been reported in the lower Norian part of the unit (Smith, 1912, 1927). Latest Triassic rocks of this area show little evidence of volcanism (Sanborn, 1960).

The Wallowa Mountains of northeastern Oregon contain another important occurrence of marine Triassic rocks, which here and in adjacent Idaho range in age from Karnian to Norian (Silberling and Tozer, 1968). Many original stratigraphic relationships have been obscured by the forceful intrusion of the Wallowa batholith. According to Nolf (1966), the middle and lower parts of the Upper Triassic section are dominantly volcanic and volcaniclastic, comprising great thicknesses of basalt flows, volcanic breccia, conglomerate, and mudstone. The sequence is overlain with possible disconformity by the Martin Bridge Limestone that contains shallow-water limestone and dolomite of Karnian to Norian age. Smith (1912, 1927) reported coral reefs in this unit, and Nolf (1966) delineated a major northeast-trending reef complex. The Martin Bridge grades upward into rocks representing deeper water environments and it is overlain conformably by Upper Triassic to Jurassic turbidites containing allochthonous slump structures. Similar Late Triassic and Jurassic rocks containing shallow-water buildups have been reported by Vallier (1974) in eastern Oregon and western Idaho.

On Vancouver Island, marine Triassic rocks are well represented (Jeletzky, 1970; Muller, Northcote, & Carlisle, 1974). Most of the Middle and part of the Upper Triassic is represented by the Karmutsen Formation, a thick sequence of basalt flows, pillow breccia and aquagene tuff with minor intercalated sedimentary rocks. The Upper Triassic (Karnian to Norian) is characterized by marine sedimentary rocks including massive shallow-water limestone. Coral faunas and other shelly invertebrates are known from this limestone (Clapp and Shimer, 1911). Later in the Triassic and Early Jurassic, terrigenous sedimentation replaced carbonate deposition and was followed by major orogenesis in the Jurassic. The sequence on parts of Vancouver Island is generally similar to that in northeastern Oregon.

Scattered islands in the Alexander Archipelago of Canada and Alaska contain marine Triassic rocks. On Gravina Island (Berg, 1973), Late Triassic sandstone and conglomerate contain granitic and Paleozoic sedimentary clasts. In addition, breccia, siltstone, argillite, and limestone are present. Some of these rocks grade laterally into basalts of Norian age. Martin (1916) and Smith (1927) have described coral reefs in the limestone. The Upper Triassic sequence on Gravina unconformably overlies older Paleozoic rocks. The stratigraphic relationships and rock types of Gravina contrast with those on the Queen Charlotte Islands, where a sequence more like that on Vancouver Island is present (Sutherland-Brown, 1968).

In the Wrangell Mountains of Alaska, near the Yukon border, is another sequence also much like that on Vancouver Island. Shallow-water Karnian to Norian limestone and dolomite disconformably overlie the Nikolai Greenstone, a thick sequence of Triassic basalt flows and pillow lavas (Armstrong, Mackenett, & Silberling, 1969).

TECTONIC MODELS AND TRIASSIC BUILDUPS

Various tectonic models have been proposed to explain the Mesozoic Cordilleran rock record. During the Triassic the western margin of North America is thought to have been the site of an active subduction zone associated with an island arc-trench system. Exact details and the mechanisms involved are not clearly understood. Evidence suggests that during the Late Permian and Early Triassic, western North America was characterized by extensive volcanism related to the accretion of island arc rocks onto the continental margin. The tectonic history from the Middle Triassic to Jurassic appears to have been the transformation of a "Japan Sea" tectonic setting to an

"Andean" type (Silberling, 1973). During the Late Triassic, shallow carbonate platforms and coral buildups became established (Silberling, 1975).

Some workers have recognized that many terranes along western North America show marked contrasts with other closely associated terranes in tectonic, stratigraphic, volcanic, and paleontologic attributes. This disparity was used by Churkin and Emberlein (1977) to support the theory that borderland terranes of the Cordilleran region are comprised of numerous lithospheric plates that are allochthonous to the North American craton. The presence of faunas with Asian affinities in the Cordilleran region suggested to Wilson (1968) and Danner (1970) that some parts of the Cordilleran region may represent fragments of Asia that have been swept onto North America. While these authors interpreted the Cordilleran region in terms of numerous fragments or microplates, each with its own unique history, other workers such as Hughes (1975) and Nur and Ben-Avraham (1977) have discussed the whole Cordilleran region as a once separate and coherent continent independent of the North American craton.

Another tectonic model presented by Jones *et al.* (1972) theorized that rocks of southeastern Alaska constituted part of a displaced terrane that was dismembered by transcurrent faulting and was displaced a considerable distance northward. Along similar lines, Jones, Silberling, and Hillhouse (1977) have defined a large terrane termed Wrangellia. They believe that Wrangellia represents a coherent fragment of North America that is one of perhaps many terranes to have undergone considerable movement relative to the rest of the continent. Post-Triassic movements northward on the order of several thousand kilometers have been hypothesized for Wrangellia.

According to this hypothesis, Triassic rocks of Wrangellia are suggested to have originated much further to the south. The Triassic rocks of Wrangellia are characterized by similarities in the stratigraphic and volcanic record.

Included in Wrangellia are Triassic exposures in the Wallowa Mountains, Oregon, on Vancouver Island and the Queen Charlotte Islands of British Columbia, on Chichagof Island, and in the Wrangell Mountains of Alaska. The vast amounts of Triassic tholeiitic basalts occurring in rocks of this terrane were presumably initiated by rifting but details are obscure. Throughout Wrangellia thick sequences of Upper Triassic carbonate rocks characterized by similar types of shelly benthonic faunas appear to be characteristic.

The only quantitative corroboration for the presumed displacement of Wrangellia comes from paleomagnetic data. According to N. J. Silberling (written commun., 1977), paleomagnetic study of Triassic rocks of Wrangellia is far from complete but nevertheless some available data from Alaska as well as Vancouver Island tends to support the displacement theory. The exact amount of relative movements and the timing of the events are still unclear and among various workers there appears to be no mutual agreement on the details.

In the present study, some of the limestone intervals containing coral buildups are situated within the Wrangellia of Jones, Silberling, and Hillhouse (1977). These occur in the Wallowa Mountains of Oregon and on Vancouver Island (Fig. 2). Areas farther to the south in northern California and in the Pilot Mountains of Nevada were also investigated. The relationship of Triassic rocks in these areas to those of Wrangellia is not clear. Upper Triassic limestone in both Nevada and California is generally similar to that of Wrangellia in lithology and faunal content but unlike Wrangellia, a thick sequence of basalt underlying the Upper Triassic carbonate complex is absent.

On Gravina Island, Alaska (Fig. 2), Upper Triassic coral-bearing limestone occurs in a sequence quite unlike that of Wrangellia. The rocks at this locality are apparently positioned east or inboard of Wrangellia, and Silberling (written commun., 1977) believes that they, like rocks of Wrangellia, are also displaced. Their relationship with Wrangellia is unknown. Another locality of this study, that at Iliamna Lake, contains the northernmost occurrence of Triassic corals (Fig. 2). Here tectonic relationships with Wrangellia are even more obscure. Jones, Silberling, & Hillhouse (1977) suggested that these rocks lie tectonically outboard of Wrangellia. Silberling (written commun., 1977) believes that they may also represent a displaced terrane. The tectonic history and relationships of the Triassic limestone at Iliamna Lake are still poorly known. Although the stratigraphy and rock types are unlike those of Wrangellia, the coral species are nearly identical.

The picture that emerges from the foregoing discussion is indeed complex. It is apparent, when considering the stratigraphic and tectonic record of the Triassic from region to region, that major differences exist. Evidence cited above suggests that Upper Triassic limestone and coral buildups of western North America have been displaced from their original sites of deposition. The coral buildups, although quite similar in composition, clearly occur in a wide variety of tectonic and depositional settings. In subsequent chapters, interpretations derived from the paleoecology, distribution of fossils, and climatic implications of the Triassic buildups will be compared with some of the above tectonic hypotheses.

DESCRIPTIVE GEOLOGY OF LOCALITIES

Results of field investigations of Triassic coral localities in Nevada, California, Oregon, Vancouver Island, and Alaska are presented. The geographic locations of the areas investigated are given in Figure 2. Descriptions of the localities are arranged according to their geographic distribution from south to north.

PILOT MOUNTAINS, NEVADA

Setting and stratigraphy.—Two stratigraphic sections were measured and studied in the Pilot Mountains near the town of Mina. These are in the lower member of the Luning Formation (Muller & Ferguson, 1936). The Luning Formation in its type locality is at least 2.5 km thick and contains a heterogeneous mixture of rock types ranging from limestone and dolomite to conglomeratic sandstone. Following the terminology of Muller and Ferguson (1939, p. 1598), rocks of the Luning can be divided into three distinct facies based on faunal associations: a nearshore pelecypod facies containing oyster banks, a coral reef facies, and a deeper water, offshore ammonite facies.

According to Muller and Ferguson (1939) the coral reef facies is exposed over a wide area within the lower member of the Luning, which is estimated to be 775 m thick. The areas of outcrop include not only the Pilot Mountains but also the Gillis Range, Garfield Hills, Shoshone Mountains, and Cedar Mountain Ranges, which are as much as 130 km north and northwest of localities in the Pilot Mountains. The coral buildups are best represented in the Pilot Mountains, where they occur at several stratigraphic positions near the top of the lower member of the Luning. According to Muller and Ferguson (1939), they occupy a consistent stratigraphic position in the lower member within an interval of 62 m. Also present in the lower member of the Luning are thin limestone beds dominated by *Ostrea montiscaprilis.*

In the present study, two sections were measured in the Pilot Mountains and designated as *MC* and *DC* (Appendix A). *DC* is on Dunlop Canyon road (Fig. 4A), and it was from this locality that Muller (1936a) described his coral "reefs." The second locality, *MC* (Fig. 4B), is located in an unnamed canyon approximately 4.8 km due east of the locality on Dunlop Canyon road. Locality *MC* was considered to be the best outcrop because it is located in one of the least structurally deformed areas of the Pilot Mountains and contains as many as five limestone buildups. These limestone beds can be traced laterally up the canyon for a distance of 1.5 km, and the sequence is interrupted by only one normal fault. At locality *MC* the reefoid limestone bodies range from 0.5 m to 5.3 m in thickness. The limestone units are separated from each other by thin shale intervals, and the sequence in which the reefoid limestone occurs is overlain and underlain by thicker shale intervals. At the top of the section a thicker, more massive limestone forms palisades at the top of the canyon. This upper palisades unit is reefoid in part and contains masses of limestone and dolomite as much as 8.2 m thick that are dominated by framework-forming corals and spongiomorphs similar to those in the lower limestone beds.

Locality *DC* contains at least five reefoid limestone units (Fig. 4A). Most of these alternate with thin shale intervals as at locality *MC*. Section *DC* is cut by a thrust fault, creating problems in documenting a complete section. Sandwiched between argillaceous intervals, commonly alternating with the coral limestone beds, are well-developed examples of the "oyster banks" described by Muller and Ferguson (1939). The oyster banks, dominated by *Ostrea,* are present at the *DC* locality but are not as well developed at the *MC* locality.

At locality *MC,* numerous short sections were measured, and the various lithofacies were mapped laterally for over 1,400 m (Fig. 5). Within each thin limestone bed, numerous lithofacies occur. The stratigraphic sequence consists of up to five thin coral buildups that thicken and thin along the outcrop and in some cases terminate abruptly. The greatest continuous exposure of a single buildup is about 400 m. Many buildups contain a sponge fauna at their base and are overlain by molluskan limestone facies.

Lithofacies.—Almost all of the carbonate rocks are fossiliferous and contain a fine-grained mud matrix. Most contain minor amounts of silt-sized quartz grains. A few of the rock types are grainstones (*i.e.,* with sparry calcite matrix). Six distinct carbonate facies are recognized: 1) sponge framestone-bindstone, 2) coral-spongiomorph framestone-bindstone, 3) mollusk-echinoderm-coral grainstone, 6) pelletoidal oolitic grainstone.

The sponge framestone-bindstone facies occurs in the reefoid limestone at both localities, but it is especially well developed at locality *MC,* occurring repeatedly near the base of each buildup. This facies is dominated by both massive upright, cylindrical sponges and incrusting or sediment-binding sponges (Fig. 6D-E). In addition to the sponges, spiriferid brachiopods are abundant in and between the sponges (Pl. 8, fig. 13). Matrix in this facies is fine-grained micrite. Minor bivalve shells are also present. This facies is thin, ranging from 20 to 150 cm in thickness.

The coral-spongiomorph framestone-bindstone facies composes the bulk of the buildups and consists of massive and branching, usually recrystallized corals and minor

spongiomorphs that together form a self-supporting framework. It is associated with a fine-grained micrite matrix. Numerous borings are evident in the corals (Fig. 6F). These range from slightly less than 1 mm to 6 mm in diameter. This facies is also represented by incrusting corals and spongiomorphs, producing thick, ribbonlike colonies with intervening fine-grained micrite between successive growths. Abundant bivalve, brachiopod, and

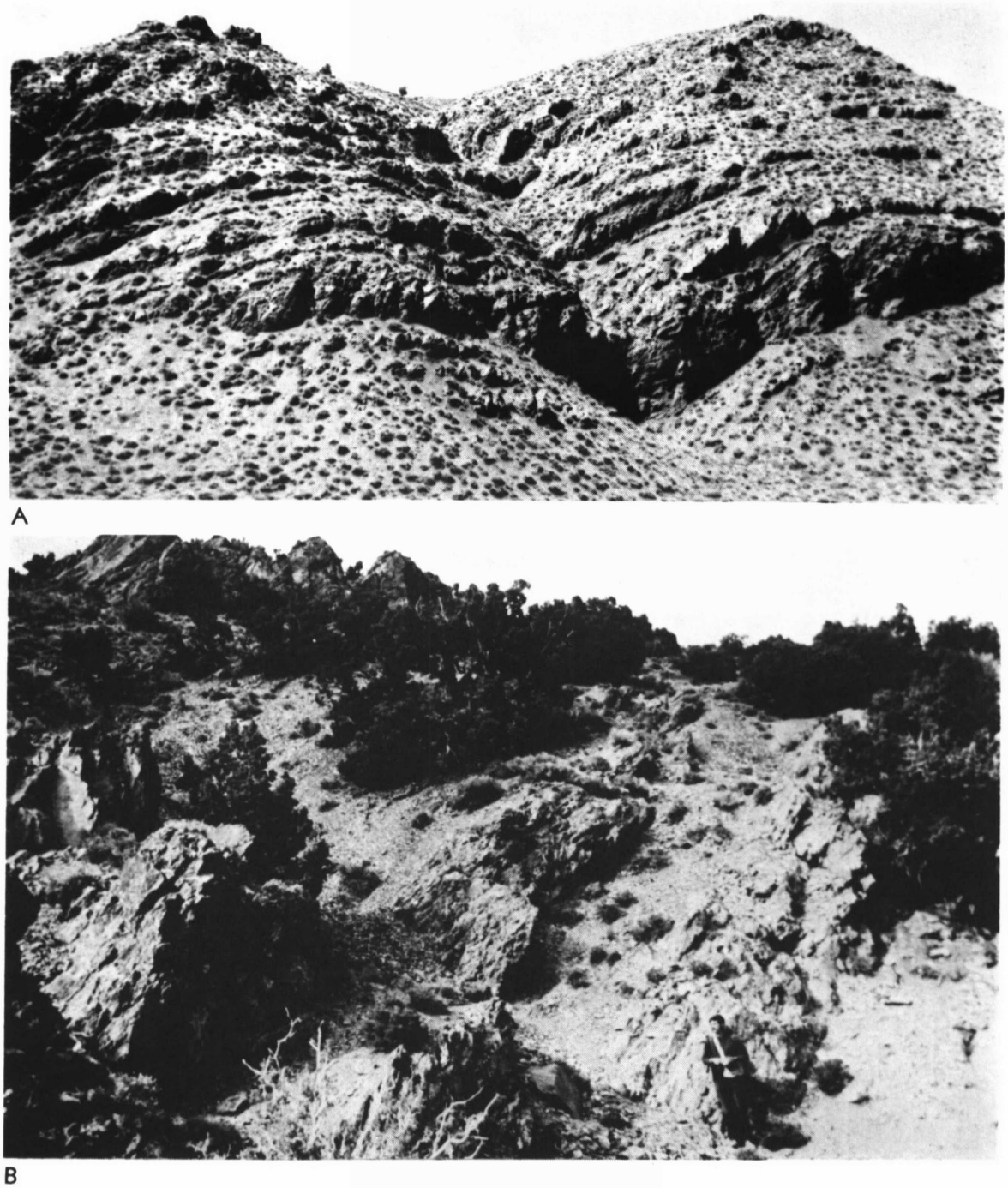

FIG. 4. Outcrops in the Pilot Mountains, Nevada.———A. Locality *DC*, showing numerous thin beds of coral limestone that alternate with shale. Lower limestone bed is approximately 10 m thick. Note how some beds thicken and thin.———B. Locality *MC*, east end of canyon, with thin beds of reefoid limestone and shale.

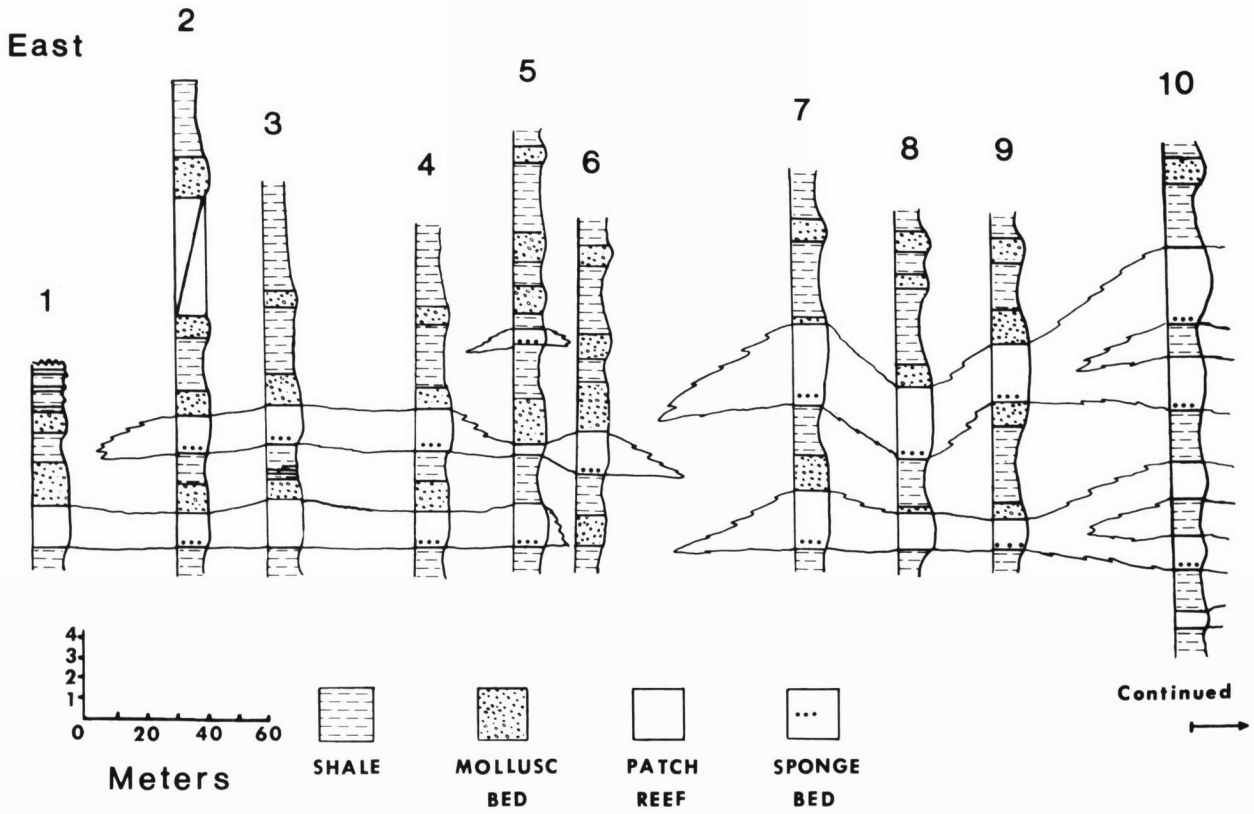

FIG. 5. See facing page.

echinoderm fragments also occur in this facies. Gastropods are present but not common. Sphinctozoan sponges are present but rare.

The mollusk-echinoderm packstone facies is characterized by abundant oysters with varying amounts of crinozoan and echinozoan debris. Small foraminifers, 0.3 to 0.6 mm in length, are present but rare in this facies. Bivalve shells are numerous, frequently fragmental, poorly sorted, and frequently stacked or nested. Other grains include brachiopod and rare fragmental coral material. Matrix is always micrite. This facies occurs rarely within the buildups, but frequently overlies them with distinct onlapping contacts. It also characterizes most of the nonreefoid limestone units. Although present at both localities, this facies is best developed at locality *DC*.

The mollusk-coral wackestone facies occurs most commonly within the reefoid limestone and less commonly within the associated nonreefoid limestone. It contains mostly broken and poorly sorted bivalve debris and coral fragments.

This facies is frequently associated with the mollusk-echinoderm packstone facies.

Only the uppermost, palisades limestone at locality *MC* contains the echinoderm-coral grainstone and the pelloidal oolitic grainstone facies. The first facies is characterized by abundant abraded, poorly sorted coral and echinoderm grains within a sparry calcite matrix. Much of this facies is recrystallized to various extents. Some grains are large and angular, approximately 1 to 3 cm in diameter, but most are only a few millimeters in diameter and are subrounded. Recrystallized coral or spongiomorph fragments appear to dominate. Echinoid spines are abundant as abraded grains.

The pelloidal oolitic grainstone facies contains abundant rounded pelloidal grains along with numerous concentrically laminated ooids. This facies appears to be moderately sorted with both pelloids and ooids in the size range of 0.1 to 0.5 mm. Minor amounts of small abraded skeletal debris are also present. Much of the detail is obscured by recrystallization that affects these two grainstone facies in varying degrees. Both facies are dolomitic, and the occurrence of bedded dolomite in the vertical measured section appears to correspond with the degree of recrystallization present. These two facies, unlike the other limestone facies, lack a fine-grained micrite matrix.

Fossils.—The coral buildups of the Luning at the

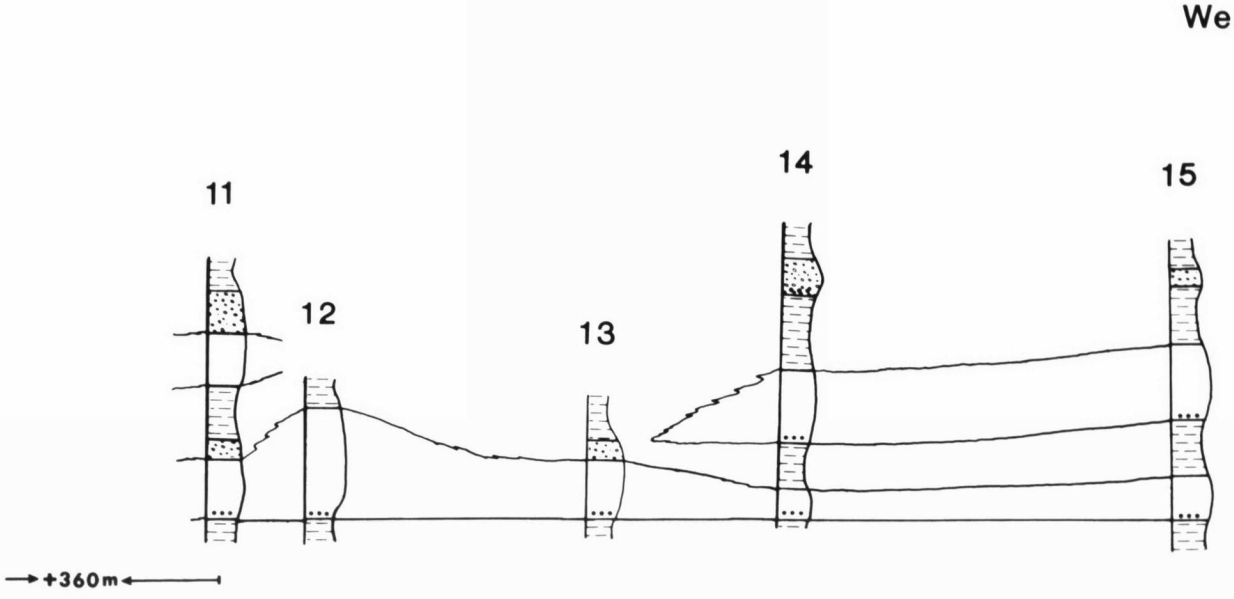

FIG. 5. Columnar sections of limestone buildups and associated rocks at locality *MC,* Pilot Mountains, Nevada, viewed from the north looking south.

Pilot Mountains contain a variety of organisms. The primary framework-constructing organisms in order of increasing abundance are scleractinian corals, spongiomorphs, and sphinctozoan sponges. Twenty-two coral, five spongiomorph, and four sponge species were identified from extensive collections made at both localities (Table 1).

Foraminifera, generally speaking, are rare in the buildups; however, five species have been observed in thin sections and tentatively identified. These occur in the bases of some of the buildups and in the nonreefoid limestones. Most are recrystallized and poorly preserved, but some tentative identifications were made from the general chamber arrangements and shapes (Table 1).

Sponges of the Luning have already been reported by Seilacher (1961), who stated that they represent a fauna not known outside of western North America. The sponges in the coral buildups include four species of chambered sphinctozoans (Table 1). The most abundant are *Polytholosia cylindrica cylindrica* (Pl. 7, figs. 4-8) and *Ascosymplegma expansum* (Pl. 7, figs. 1-3). *Polytholosia* is a large cylindrical sponge that grew upright, reaching 5 to 7 cm in diameter and up to 40 cm in height. Commonly, the sponges occur as small masses, cemented together in life positions at the base of the buildups (Fig. 6D). *Ascosymplegma* is a large, incrusting, chambered sponge approximately 1 to 2 cm thick, which extends over large areas, occurring generally parallel to the bedding (Fig. 6E). This sponge was observed in several places in the buildups to extend more than 100 cm in length. In addition to growth parallel to the sediment surface, *A. expansum* was occasionally observed to fold back and grow completely over itself (Pl. 7, fig. 2). *A. expansum* was thought to be restricted to Nevada until Dieci, Antonacci, and Zardini (1968) reported it from Middle to Upper Triassic limestones of the Italian Dolomite Alps. In the Luning, these sponges appear in great numbers at the base of the buildups.

The corals display several growth forms that include solitary, regularly branching, thin, irregularly incrusting, and more massive-platy forms. *"Montlivaltia"* displays a solitary growth form and is represented by two species, *"M." norica* and *"M." marmorea*. The generic names *"Thecosmilia"* and *"Montlivaltia"* are placed in quotation marks herein because Cuif (1974a) has shown that these two genera may not actually be present in the Triassic. Both are wide, conical, cup-shaped corals, the former reaching 4 to 6 cm in diameter. Astrocoeniid colonial

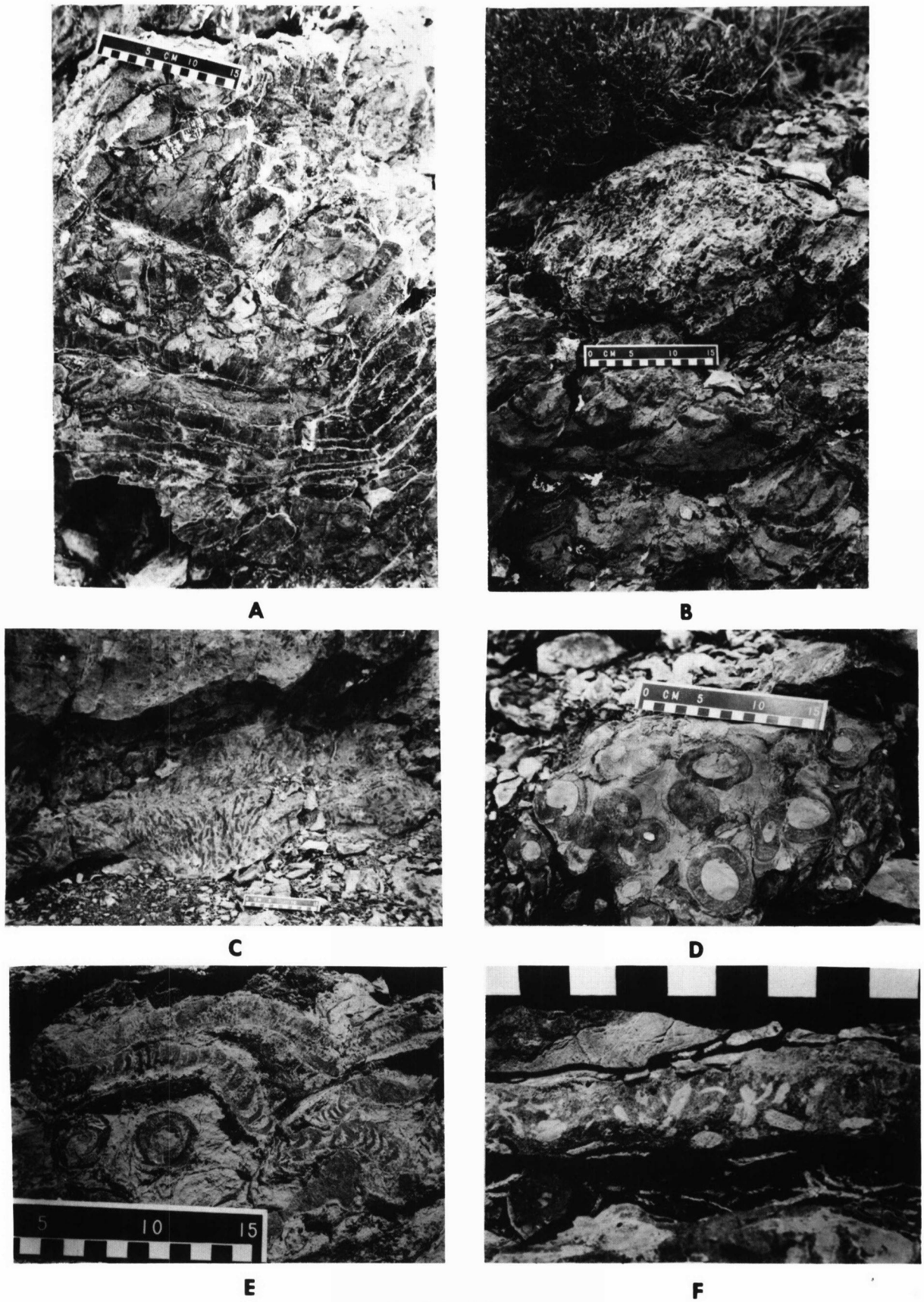

FIG. 6. See facing page.

TABLE 1.—*Fossils from Coral Buildups in the Luning Formation of the Pilot Mountains, Nevada.*

FORAMINIFERA
Marginulina sp.
Spiroplectammina sp.
endothyrid cf. *Endothyra*
uniserial form cf. *Nodosaria*
indet. involute globose form

PORIFERA
Sphinctozoa
Ascosymplegma expansum Seilacher
Polytholosia astoma Seilacher
P. cylindrica cylindrica Seilacher
P. c. dialata Seilacher

COELENTERATA
Hydrozoa
Heptastylis cf. *H. stromatoporoides* Frech
Spongiomorpha dendriformis (Smith)
S. gibbosa (Frech)
S. cf. *S. minor* Frech
S. tenuis (Smith)
Scleractinia
Actinastraea juvavica (Frech)
A. martini (Smith)
A. shastensis (Smith)
A. cf. *A. waltheri* (Frech)
Astraeomorpha confusa (Winkler)
A. confusa var. *minor* (Frech)
Elysastraea cf. *E. austriaca* (Frech)
E. cf. *E. norica* (Frech)
E. parva (Smith)
E. profunda (Reuss)
Margarastraea cf. *M. eucystis* (Frech)
M. cf. *M. norica* (Frech)
"Montlivaltia" marmorea Frech
"M." norica Frech
Palaeastraea cf. *P. descussata* (Reuss)
Pinacophyllum cf. *P. parallelum* Frech
Thamnasteria borealis Smith
T. norica Frech
T. rectilamellosa Winkler
T. smithi Squires
"Thecosmilia" cf. *"T." delicatula* (Frech)
"T." cf. *"T." fenestrata* (Reuss)
"T." cf. *"T." norica* Frech

BRACHIOPODA
Spirifera (*Spiriferina*) *alia* Hall and Whitfield
Spondylospira sp.
Zugmayerella incinata (Schafhaeutl)
spiriferids (nonlaballid) cf. *Spirigera*
indet. terebratulids cf. *Plectoconcha* and *Terebratula*
indet. rhynchonellids cf. *Rhynchonella*

MOLLUSCA
Bivalvia
Avicularia cf. *A. sayeri* Smith
Cardinia sp.
Cassianella sp.
Halobia sp.
Ostrea cf. *O. montiscaprilis* (Emmrich)
Ostrea sp.
Posidonia sp.
Septocardita sp.
Trichites sp.
indet. pectinids
indet. mytiliform sp.
indet. small nuculoid sp.
Gastropoda
indet. small high spired forms
indet. large trochoid forms
Cephalopoda
Paranautilus sp.
Pleuronautilus sp.

ARTHROPODA
Ostracoda
indet. ostracodes

ECHINODERMATA
Echinoidea
indet. cidarid spines
indet. echinoid plates
Crinoidea
Encrinus columnals and plates
Isocrinus columnals and plates

VERTEBRATA
numerous large bone fragments
vertebrae identified as ichthyosaur remains

corals are well represented in the coral buildups. Four species of *Actinastraea* are recognized and all but *A. martini* are common to abundant. *A. juvavica,* which has thin incrusting coralla, is volumetrically significant in the buildups (Pl. 1, fig. 7). *A. shastensis* (Pl. 1, fig. 9) is a common, more massive colonial coral. *A. waltheri* (Pl. 1, fig. 6) frequently occurs with *A. shastensis.*

Thamnasteriid corals are among the more conspicuous elements in the reefoid limestones of the Luning. Four species of *Thamnasteria* are present but only *T. rectilamellosa* (Pl. 1, fig. 12) and *T. smithi* are volumetrically significant. *T. rectilamellosa* forms small, flat, disc-shaped colonies averaging about 8 cm in diameter and about 1 to 2 cm in thickness. Sometimes this species also assumes a broad platy growth form (Pl. 2, fig. 1). *T. norica* has a thicker, more massive-platy growth form, reaching 80 cm in diameter and 10 cm in thickness. *T. borealis* produces long parallel branches, which are rare, and in areas where the limestones are recrystallized

FIG. 6. Coral buildups in the Pilot Mountains, Nevada.———A. Vertical outcrop of a patch reef showing the abundant stacked, platy corals (dark) that form a framework in the limestone.———B. Top part of a coral succession showing numerous platy and incrusting corals that are overlain by rounded masses of *"Thecosmilia."*———C. *"Thecosmilia"* clusters at top of a patch reef. Note how corals are irregularly overlain by limestone bed at top, which contains abundant bivalve shells.———D. Broken limestone fragment from base of buildup showing numerous cylindrical sponges *Polytholosia cylindrica.* Some of these are cemented to produce framework structures.———E. Sponge zone at base of a patch reef. Vertical outcrop reveals outlines of numerous sponges *Polytholosia cylindrica* and irregularly incrusting *Ascosymplegma expansum.*———F. Close view of recrystallized, platy coral colonies that show evidence of numerous borings. Scale in centimeters.

they could be easily mistaken for a *"Thecosmilia"* colony. Small disclike colonies of *Astraeomorpha* 2 to 5 cm in diameter are common (Pl. 1, fig. 11).

At least three species of *"Thecosmilia,"* a branching colonial coral, are well represented in the buildups, often contributing significantly to the framework construction. Only specimens of *"T."* sp. cf. *T. norica* are well preserved. Most other specimens are so recrystallized that little detail other than general shape is preserved. Two additional species appear to be present, *"T."* cf. *"T." fenestrata* and *"T."* cf. *"T." delicatula*. *"T."* cf. *"T." fenestrata* is a large coral with branches 8 to 12 mm in diameter (Pl. 3, fig. 1). It branches from a central point and forms low, bushlike forms 60 cm in height that may reach 150 cm in diameter at the top. Sometimes these occur together, often on top of one another, to form small clusters along the tops of buildups. *"T." delicatula* is smaller, with branches 3 to 5 mm in diameter (Pl. 3, fig. 5). It branches rapidly to form generally small colonies, usually 30 cm high and 60 cm wide at the top, but examples were observed that reached 60 cm in height and 250 cm in width. Although these two species usually occur separately, they were occasionally observed in association. *Margarastraea norica* (Pl. 4, fig. 1) and *M. eucystis* (Pl. 4, fig. 2) are rather large colonial corals.

Four species of *Elysastraea* were recorded from the buildups. *E. profunda,* a large, incrusting colonial coral, is particularly conspicuous. *E. parva,* a form with smaller corallites, is common (Pl. 3, fig. 7). *E. vancouverensis* was recorded by Muller (1936a), but this species was not recognized in the collections from the two localities. Species of *Elysastraea* in North America appear to be little differentiated from one another except in size of the corallites, and there appears to be considerable morphologic intraspecific gradation as pointed out by Squires (1956). *E.* cf. *E. austriaca,* an exceedingly rare form, is tentatively recognized for the first time in North America. *Palaeastraea descussata* (Pl. 4, fig. 4) is a common coral which assumes an irregularly incrusting growth form.

Spongiomorphs are conspicuous in the coral buildups, commonly contributing to the framework. Only in local beds, however, do they rival the corals in abundance. Three species of *Spongiomorpha* and one species of *Heptastylis* were recognized in the Luning. These were not previously reported by Muller (1936a). *Stromatomorpha californica* mentioned by Muller (1936a) was not found. Most of the spongiomorphs are largely recrystallized and thus difficult to identify. *Spongiomorpha tenuis* (Pl. 6, figs. 1, 2) occurs as rounded "heads" approximately 6 cm in diameter. *Spongiomorpha gibbosa* is quite abundant in the buildups, occurring as thick branching forms 10 to 12 cm long or as irregularly incrusting masses several cm thick (Pl. 5, figs. 1-4). *Heptastylis* occurs frequently as small dish-shaped or mushroomlike masses with convex surfaces, 6 to 8 cm in diameter and 1 to 2 cm thick (Pl. 5, fig. 6). *S. dendriformis* is a large, branching spongiomorph that resembles some of the smaller *"Thecosmilia"* in general shape. Flügel and Sy (1959) questioned whether *S. dendriformis* is in fact a true hydrozoan. Although the spongiomorphs usually occur in close association with the corals, some limestone beds contain concentrations of spongiomorphs, largely without corals.

Spiriferid, terebratulid, and rhynchonellid brachiopods (Pl. 8, figs. 5, 6, 8, 9) are common in the limestone beds of the lower member of the Luning, but spiriferids, represented by *Zugmayerella incinata* (Pl. 8, figs. 10-13) and *Spondylospira* sp., dominate in the reefoid limestones. These spiriferid brachiopods are associated with the sponges and they occur in great concentrations in coral cavities and as debris between massive corals and sponges. Some spiriferids appear to be attached to corals although exact relationships are difficult to document. Peter R. Hoover, who has been investigating these brachiopods, theorizes that they could have been capable of attachment with a functional pedicle (pers. commun., January, 1976). Specific assignments of the rhynchonellids and terebratulids must await detailed serial sectioning.

A variety of bivalves is present in the buildups. These include *Ostrea* sp. cf. *O. montiscaprilis,* which is present in many of the reefoid limestone buildups but dominates in adjacent oyster beds. Very large, mytilid bivalves of the genus *Trichites* occur abundantly in the oyster beds as well as in the coral buildups (Pl. 9, fig. 1). These bivalves appear to have been byssally attached forms. Their presence in the Triassic of North America was made known by Stanton (1926). Previously they had been recognized only in the Jurassic and Cretaceous of Europe. Other bivalves associated with the buildups include small pectinids that have not been identified. Additional taxa are listed in Table 3.

Gastropods are not common in the sequences measured but occur in local abundance in some of the coral framework, particularly in association with the *"Thecosmilia"* colonies. All specimens collected were extensively recrystallized or preserved only as internal molds.

Cephalopods are extremely rare in the buildups. Only two specimens were collected during the study, and these were both nautiloids (Table 1). As commented on by Muller and Ferguson (1939), ammonites are entirely absent from the "coral reef facies," but they do occur in the shales above and below the reefoid limestone.

Few identifiable crinozoans or echinozoans are represented. Unidentifiable loose columnals, plates, and spines are common (Pl. 9, fig. 10) and at least two genera of crinozoans were identified (Table 1). Echino-

zoans are also poorly preserved and occur as rare scattered plates and spines. Crinozoan material is common in the buildups but it is volumetrically more abundant in the nonreefoid limestone types associated with the buildups. Some of the molluskan-dominated limestones contain abundant columnals (Pl. 9, fig. 10).

Notable in both the reefoid limestone and the associated shale are large bone fragments and vertebrae belonging to the ichthyosaur group of marine reptiles. The identification was made by Dr. Larry D. Martin of the Museum of Natural History, University of Kansas. The dimensions of the bones indicate that these reptiles were of considerable size and weight. Many of the bones occur in distinct beds along the bases of the buildups and are associated with oysters and sponges. Some are heavily incrusted by oysters and sponges. Other material was collected from shale beds overlying and underlying the buildups.

The biota of the reefoid limestone of the Luning can be categorized according to ecologic roles. These categories are 1) framework builders, 2) binders or cementers, and 3) debris producers. The massive and branching corals and spongiomorphs represent the framework builders, the binders include incrusting corals and spongiomorphs. The incrusting spongiomorphs function as cementers while debris is produced by brachiopods, bivalves, corals and spongiomorphs. Spiriferid brachiopod shells constitute a portion of the debris in the buildups. Some evidence of boring is present in the coral framework (Pl. 5, fig. 5; Pl. 9, fig. 9), and boring is believed to account for much of the debris in the buildups.

A limited amount of grid counting was undertaken in the field to estimate relative abundances of the major taxonomic groups in the buildups (Table 2). Due to poor exposures, only three counts were made on each rock type. While the results do not represent a large sample size, they do provide a rough idea of the contributions of each group per unit area. The precentage figures appear to confirm preliminary qualitative observations on abundances. Large corals and spongiomorphs are recrystallized, frequently preventing generic or specific identifications. In such cases, only general growth forms were identified.

Corals are the most abundant organisms in the coral-spongiomorph framestone-bindstone facies (Table 2), making up between 45 and 54% of the assemblages. Incrusting corals dominate in the three counts. Spongiomorphs are next in abundance (13 to 22%), followed closely by spiriferid brachiopods (11 to 20%). In the *"Thecosmilia"* clusters, the branching coral *"Thecosmilia"* dominates (78 to 90%), with mollusks more in abundance than spiriferid brachiopods. The large incrusting sponge *Ascosymplegma* occurs in the sponge framestone-bindstone facies (40 to 51%) with spiriferid brachiopods in greater abundance (31 to 35%) than in the other facies.

Discussion.—From the measured stratigraphic sections and the information on the biota and carbonate facies, it is obvious that the vaguely defined "coral reefs" of Muller (1936a) are not the thick, well-developed limestone masses usually associated with the term "reef." They are instead rather thin, low, patchlike mounds of limestone containing a reefoid framework. The thickest occurrence is just over 9 m, the thinnest occurrence 1.5 m thick. Nowhere in the area are thick, massive, reef limestones known. Although thin and lacking the massive nonbedded characteristics of many ancient reefs, the buildups of the Luning contain a diverse association of framework-building corals and spongiomorphs, which by Heckel's (1974) definition (Fig. 3) would be assigned to the category of an organic framework reef because they form potential wave-resistant structures. Based on the facies laterally associated with these reefoid limestones, it is evident that they attained only minor relief (1 to 4 m) above the surrounding sediment sur-

TABLE 2.—*Percentages of Major Fossil Groups Shown by Point Counts in the Luning Coral Buildups, Pilot Mountains, Nevada.* Counts made on three buildup bedding planes using a 25-by-25-unit wire grid (unit size 1.25 cm^2).

Fossil Group	Coral-Spongiomorph Framestone-Bindstone			*"Thecosmilia"* Clusters			Sponge Framestone-Bindstone		
	1	2	3	1	2	3	1	2	3
Ascosymplegma (sponge)	5.4	12.2	4.1	.....	.....	.....	50.8	47.0	40.0
Polytholosia (sponge)	.....	.....	.....	.....	.....	.....	10.1	12.2	5.0
Thick, platy corals	5.2	12.5	22.3	.....	.....	.....	.....	.....	.....
Incrusting corals	40.1	37.0	32.0	.....	.....	.....	4.0	.....	8.0
Branching *"Thecosmilia"*	.....	.....	.....	77.6	84.5	89.7	.....	.....	.....
Spongiomorphs	21.7	15.1	13.9	.....	.....	.....	2.1	5.2	7.8
Spiriferid brachiopods	20.0	11.6	19.5	4.2	.....	.....	31.0	33.1	35.1
Nonspiriferid brachiopods	6.3	3.5	.....	.....	.....	.....	2.0	3.5	5.0
Gastropods	1.3	4.0	.....	7.0	10.2	6.5	.....	.....	.....
Bivalves	.....	5.0	8.2	11.2	5.3	4.8	.....	.....	.....

face (Fig. 5), but judging from the development of adjacent facies, they must have exerted some degree of control over surrounding environments.

Some of the most obvious and striking features about these buildups are 1) their lack of wave-washed talus such as flanking beds, 2) the predominance of a fine-grained (micrite) matrix, and 3) the lack of calcareous algae. Such characteristics suggest that these buildups developed in calm, deep water. Absolute depths cannot be assigned, but it was certainly below effective wave base as evidenced by textural features of the carbonates and the lack of wave-washed talus. The absence of algae could indicate either cold water or depth below the effective photic zone. Although this depth is generally about 60 to 70 m, it can be raised considerably by turbidity. The effect of finely suspended particulate matter in altering the depth of sunlight penetration should be considered. These effects coupled with high rates of sedimentation can produce distinct responses in the zonation of light-sensitive benthic invertebrates. Zoned associations of living corals and sponges characteristic of relatively deep water have been reported in Jamaica at anomalously shallow depths due to reduced light conditions created by high sedimentation rates (Stanley, 1975; Bonem & Stanley, 1977). These living patch reefs show a remarkable similarity in thickness, zonation, and composition to the buildups of the Pilot Mountains.

The small limestone buildups of the Pilot Mountains are relegated to a subcategory of "Potential Reefs" (Fig. 3). Although they possess framework and thus the poential for reef development, they lack the diagnostic shallow-water attributes of true reefs. On the other hand, they are not thought to have developed at any great depth (*i.e.,* abyssal slope) because at locality *MC,* limestone with oolites and other sedimentary and textural features indicative of shallow water occurs only 20.6 m above the highest coral bed (see locality *MC,* measured sections, units 15-18, Appendix A).

Judging from the stratigraphic relationships, the buildups appear to have been ephemeral. Development and extermination occurred at least five or six times. They appear to have existed contemporaneously with oyster banks as well as during deposition of the fine-grained shale. Extermination of the buildups occurred periodically, as evidenced by their gradual covering over by molluskan shell beds. These beds are succeeded by the intervening relatively unfossiliferous shales, indicating cessation of carbonate deposition. This cycle was repeated at least three times.

Within the buildups, definite cycles of small scale biogenic succession are evident (Fig. 7). These consist of initial colonization and stabilization of the mud substrate by the sphinctozoan sponges and brachiopods, as observed by Seilacher (1961). Next, massive and incrusting corals and spongiomorphs developed on the hard substrate provided by the sponges. The final stage in many cases was the development of clusters of the branching coral *"Thecosmilia"* at the top of the buildups. Many of these clusters are irregularly overlapped by molluskan debris consisting of numerous shells of *Ostrea* and *Trichites.*

The ephemeral buildups of the Luning indicate development in unstable conditions during subsidence and frequent influx of fine terrigenous sediment. The repeated alternations of shale and limestone in the lower member of the Luning suggest cycles of sedimentation, with times of rapid subsidence and influx of fine terrigenous clastics alternating with times of more stable, clearer water conditions, the latter facilitating the development of the thin buildups.

Age.—The age of the coral buildups in the Pilot Mountains has been a matter of dispute. Smith (1927) placed them in his lower Norian reef zone but Muller (1936a), on the basis of both ammonite and molluskan faunas, insisted that they were older, and assigned them to the Karnian. Muller and Ferguson (1939) regarded the Luning Formation as an equivalent of the Karnic stage of the European section. More recent work (Silberling and Tozer, 1968) placed the Luning well into the Norian.

Silberling (pers. commun., March, 1977) placed the coral buildups between the Kerri and Magnus zones in the early Norian on the basis of ammonite zonations. According to him, none of the Luning is older than earliest Norian in the Pilot Mountains, but the same formation is as old as late Karnian elsewhere. The brachiopod *Zugmayerella uncinata,* which characterizes the buildups, is known in the European Norian and Rhaetian stages and also from the Norian of North America (P. R. Hoover, pers. commun., January, 1976). On this basis, I assign the buildups of the Luning to the lower Norian.

NEW PASS, NEVADA

Setting and stratigraphy.—In the New Pass Range of central Nevada, corals occur in a thick Triassic limestone unit termed the Augusta Sequence by Silberling and Roberts (1962). This sequence ranges in age from Early to Late Triassic. "Coral reefs" were reported as Ladinian in age by Muller (1936a, p. 206). They occur in the Augusta Mountain Formation, a unit characterized mainly by shale and limestone. The best exposures of this unit are near New Pass Mine in South Canyon (locally known as Bull Canyon). In this canyon a steeply dipping section of the Augusta Mountain Formation is exposed and has been well studied, primarily because of its biostratigraphic importance (Johnson,

1941; Silberling, 1956). This is the site where Muller (1936a) described "coral reefs."

A generalized stratigraphic column of these rocks and the coral zone was illustrated by Silberling (1956), and an excellent map was published by MacMillan (1972). MacMillan described the coral zone as occurring in the lower member of the Augusta Mountain Formation. He described the limestones as crinoid-bivalve-coral biosparite and interpreted them as a biostromal facies associated with abundant oolites and algae. The lower member is approximately 500 m thick but the coralliferous beds are thinner and occur near the base.

The section in South Canyon which contains the rich coral assemblage was described and sampled (Appendix B). Although corals occur throughout the lower member of the Augusta Mountain Formation, they are concentrated only in an interval approximately 19 m thick. Two units within this interval contain abundant corals and mollusks but the corals are scattered throughout

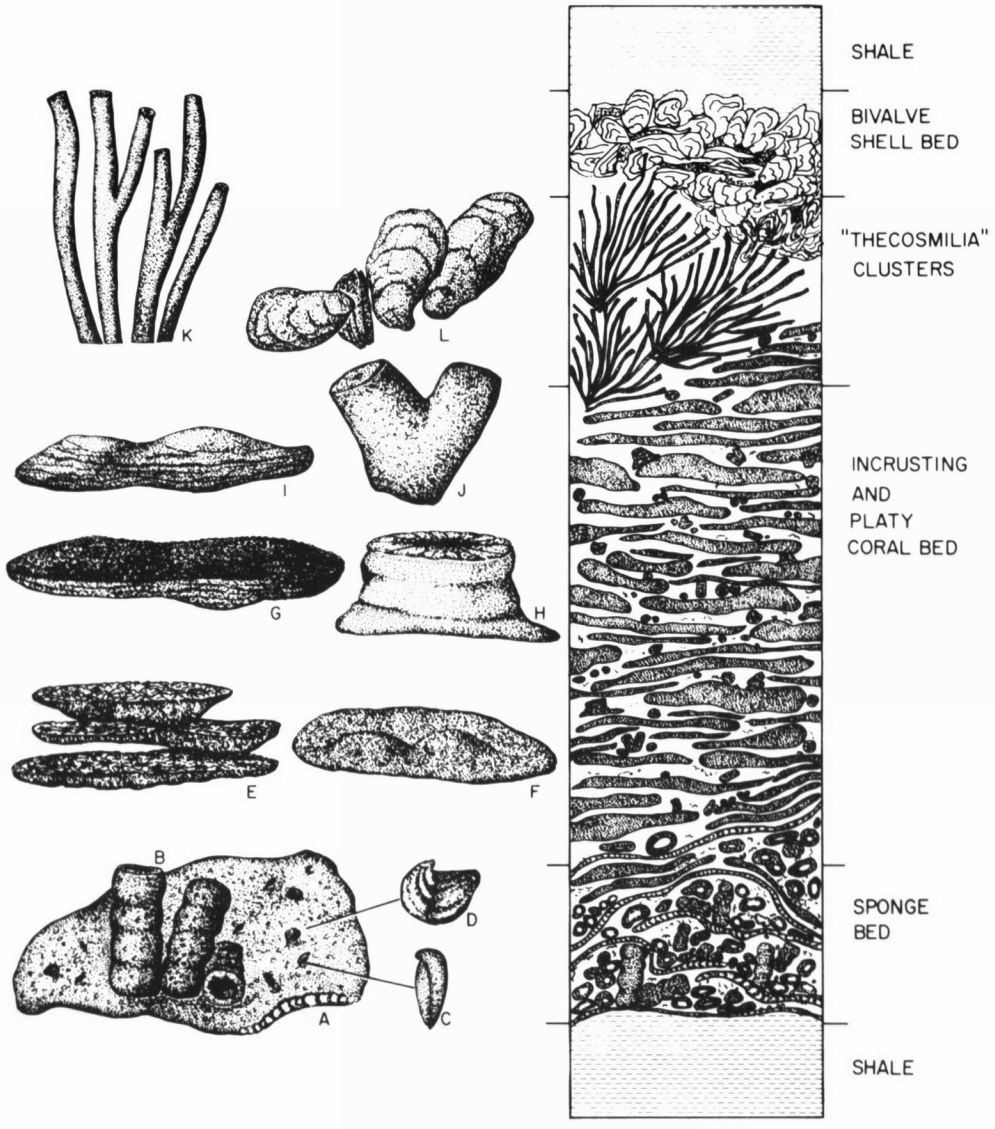

FIG. 7. Biotic succession in buildups of the Pilot Mountains, Nevada. To the left of columnar section are schematic drawings of fossil organisms that contributed to the buildups. These are: A, *Ascosymplegma* (calcisponge); B, *Polytholosia* (calcisponge); C, rhynchonellid brachiopod; D, terebratulid brachiopod; E, *Thamnasteria* (coral); F, *Palaeastraea* (coral); G, *Elysastraea* or *Actinastraea* (corals); H, *"Montlivaltia"* (coral); I, incrusting spongiomorph; J, branching spongiomorph; K, *"Thecosmilia"* (coral); L, *Ostrea* (bivalve). Drawings not to scale.

individual limestone beds and do not form a reefoid framework. These limestone beds were correctly characterized as "biostromal" by MacMillan (1972) owing to a lack of thickening in the bedded sequence.

Lithofacies.—Most of the rocks in the studied interval are very coarse-grained, bioclastic calcarenites. Most of the carbonates studied in thin section are grainstones, *i.e.*, spar matrix with abundant allochems of fossil grains, intraclasts, and oolites. Two general facies were distinguished: a mollusk-echinoderm grainstone facies and a coral-mollusk bindstone-packstone facies.

The mollusk-echinoderm grainstone facies is characterized by well-sorted, spar-cemented grains, particularly whole and abraded bivalve shells, gastropods, and echinodermal debris. Pellets and rounded clasts up to 4 mm in diameter are common. Algal-coated grains are common and red algae are very conspicuous both incrusting grains and as free, rounded grains 3 to 10 mm in diameter. Endothyrid and possible rotaliid foraminifers are common in some of the intervals. Oolitic beds are particularly conspicuous in the sequence and contain concentrically laminated oolites up to 1 mm in diameter. Coral fragments are common in this facies but do not form a major constituent. The coral-mollusk bindstone-packstone facies contains abundant corals and mollusks, particularly pectinid bivalves and large, high-spired gastropods. Where corals are particularly abundant, pectinids occur in small localized beds made up of coral incrustations or overgrowths. The limestone types between these overgrowths are fine-grained biomicrites containing abundant coral and molluskan grains.

Fossils.—The biota of the coralliferous limestone (Table 3) consists of abundant scleractinian corals and mollusks. Foraminifers are common in many thin sections, but they are not abundant. A few thin, incrusting sphinctozoan sponges were collected, but were not identified.

Scleractinian corals are abundant but lack the diversity present in most of the other localities. Four species were identified. Unfortunately, many of the corals are poorly preserved and difficult to identify. The genus *Actinastraea* dominates. Two species of *Actinastraea* were identified but these are not referred to any particular species.

Species 1 is a large *Actinastraea* with corallite diameters between 2 and 3.5 mm and three cycles of septa. It is abundant, forming large, elongate, platy colonies as much as 75 cm long and 20 cm thick. Most colonies, however, are only 20 to 30 cm long and 3 to 10 cm thick. Most colonies are slightly convex upwards, forming ellipsoidal plates thickest in the center and tapering toward the periphery. This coral has corallites in the same size range as *Elysastraea profunda* and where recrystallized could be mistakenly identified as this species.

TABLE 3.—*Fossils from New Pass, Nevada.*

FORAMINIFERA
indet. endothyrids and ?rotaliids
PORIFERA
indet. incrusting sphinctozoan sponge
COELENTERATA
Actinastraea sp. 1
A. sp. 2
Astraeomorpha sp.
Cassianastraea cf. *C. reussi* (Laube)
Elysastraea sp. A
BRACHIOPODA
indet. ?terebratulids
MOLLUSCA
Bivalvia
Cardinia
Lima cf. *L. striata* (Schlotheim)
Limatulella sp.
Ostrea sp.
indet. actinodontophorids
indet. megalodonts
indet. myalinids
indet. small nuculids
indet. pectinids
Gastropoda
Allocosmia sp.
indet. high-spired
indet. pupiform
ECHINODERMATA
indet. crinoid columnals
indet. echinoid plates and spines
ALGAE
Solenopora sp.
indet. incrusting ?blue-green algae

Actinastraea species 2 is a smaller form with corallites 1.5 to 2 mm in diameter with at least two cycles of septa. Although appearing to differ in number and arrangement of the septa, it strongly resembles *A. juvavica* (Frech), and may have been the species referred to by Muller as *Stephenocoenia juvavica*. *Actinastraea* species 2 assumes irregularly incrusting growth forms. The dimensions of the colony are variable but average 15 cm in length and 1 to 2 cm in thickness.

Specimens of *Elysastraea* are present but poorly preserved and not assigned to a species. The corallites have about the same general size as those of *E. vancouverensis* (Clapp and Shimer) but necessary details of the septa were absent. This coral has a thick incrusting growth form, 10 to 20 cm in length and 0.5 to 1 cm thick, and is a common species. *Cassianastraea* has been tentatively identified from a single specimen. It is a thin incrusting form, similar to *C. reussi* (Laube). *Thamnasteria* is not present at New Pass but a similar coral, *Astraeomorpha,* is rare. These are very small, disclike forms 1 to 6 cm in diameter which resemble *A. confusa* (Winkler).

Most conspicuous mollusks are pectinid bivalves that resemble *Lima* cf. *L. striata* (Schlotheim). A variety of

large gastropods is present but these are preserved only as internal molds. Brachiopods are rare in the section studies but in one place a possible terebratulid was noted.

Discussion.—It is clear from the nature of these corals that they did not constitute a true reef and should instead be classified as thin biostrome buildups probably associated with a larger carbonate bank. One of the most obvious facts about the coral buildups is the low diversity of coral taxa and the absence of branching *"Thecosmilia"* and solitary *"Montlivaltia,"* which are so conspicuous at other localities. The coral fauna is dominated by irregularly incrusting and flattened, platy corals similar in growth form to those at the Mina locality. Completely absent are the spongiomorphs that are so well developed at Mina.

It is obvious from the textural features of the limestone facies, the presence of oolite beds, and the abundant algae, that shallow and probably warm-water, high-energy conditions prevailed. This was also the conclusion of MacMillan (1972), who interpreted the rich algal-molluskan biota as existing on a broad, shallow-water carbonate bank.

Age.—The age of the coral occurrences at New Pass is well established. Muller (1936a) assigned them to the Ladinian. Later, Silberling (1956) and Silberling and Tozer (1968) provided more detailed biostratigraphic documentation placing the corals in the upper part of the Ladinian near the Ladinian-Karnian boundary. This assignment is based on the occurrence of the early Karnian ammonite *Trachyceras* (*Trachyceras*) *desatoyense* and associated fauna in strata well above the coral beds. The occurrence of *Paratrachyceras sutherlandi* and other characteristic ammonites above and below the coral-bearing limestone is indicative of the latest Ladinian.

Although this locality contains some corals remarkably similar in general morphology to corals at Mina, differences are obvious. Further assessment of better preserved coral specimens from New Pass may ultimately reveal more concerning their taxonomy.

LAKE SHASTA, CALIFORNIA

Setting and stratigraphy.—Around the Lake Shasta region in the easternmost Klamath Mountains, northern California, there is Triassic limestone referred to as coral reefs (Smith, 1912; 1927). These occur in the Hosselkus Limestone where Smith recognized a coral zone directly overlain by a *Spiriferina* brachiopod zone. The total thickness of both zones is about 30 m. Smith (1927) indicated several localities where the coral zone was well developed. The coral species were described and illustrated, and the coral associations were designated as a reef. Although Smith listed the species making up the reef, he gave little information on the textures, shapes, and thicknesses of the enclosing limestone.

I found the thickness of the Hosselkus at the Lake Shasta area to be difficult to measure due to dense vegetation and structural complications. Sanborne (1960) has shown the thickness to be highly variable, ranging from 6.1 m to as much as 86 m. The Hosselkus is overlain and underlain by thick shale sequences. The type area of the Hosselkus Limestone is near Taylorville, California, 130 km to the south. There are some stratigraphic and nomenclatural problems in carrying the name Hosselkus Limestone to limestone in the Shasta County area from the type section (Reeside *et al.*, 1957, p. 1471; Silberling, 1959, p. 211).

The coral reefs described by Smith (1927) are difficult to locate. The localities cited by Smith as examples were at the junction of Cedar and Little Cow creeks and on the North Fork of Squaw Creek. The first locality is at SE¼, SE¼, sec. 36, T. 2 N., R. 1 W. (U.S.G.S. Bollibokka Mountain, 15 minute topographic map series). This locality was found to contain massively bedded, fine-grained limestone with abundant spiriferid brachiopods, but the coral zone was not observed. At this location along State Highway 299, the road appears to have been built up from its original level along the creek and the coral zone if present locally may have been covered. The second locality cited by Smith along Squaw Creek is no longer accessible because the area has been flooded by the Army Corps of Engineers waterways project and dam.

Extensive investigations were conducted along numerous exposures of the Hosselkus at Devil's Rock (sec. 33, T. 35 N., R. 2 W.) and at Grey Rocks (sec. 5, T. 34 N., R. 2 W.), but these yielded no evidence of corals or "coral reefs." Most of the limestone is extensively recrystallized, poorly exposed, and covered by dense vegetation. At one locality on the high cliffs above the Squaw Creek Ranger Station (sec. 21, T. 35 N., R. 2 W.), extensively recrystallized colonies of *"Thecosmilia"* cf. *"T." fenestrata* and *"T."* cf. *"T." delicatula* 30 cm high and 45 cm wide were observed in a steeply dipping exposure of the Hosselkus. Incrusting corals, *Actinastraea* cf. *A. juvavica,* and *A. shastensis,* are present. The corals occur in massive, fine-grained limestone approximately 10 m thick and are overlain by 12 m or more of bioclastic, massively bedded limestone containing abundant large spiriferid brachiopods, *Zugmayerella* cf. *Z. uncinata* (Schafhaeutl), and crinoid columnals. This poorly preserved section appears to be part of Smith's coral and *Spiriferina* zones. The corals do not form a framework structure within the limestone but instead appear to resemble the thin bostromal beds at New Pass. Due to the high dip of the strata, the units could not be traced laterally. It is not certain how typical or representative this section is of Smith's coral zone. However this locality is clearly not a reef in the sense used in the present

study. Obviously further efforts are needed in order to document this coral fauna in the area. Smith (1927) identified 14 species of corals in addition to species of spongiomorphs and brachiopods. In the present study only a few of the corals listed by Smith were found.

Lithofacies.—The carbonate facies of the Hosselkus have been studied by Sbeta (1970), who reported a variety of limestone and dolomite facies and identified nine carbonate facies from study of thin sections. These are: 1) micrite, 2) intramicrudite, 3) biomicrudite, 4) pelmicarenite, 5) pelspararenite, 6) biopelspararenite, 7) intrasparrudite, 8) crinoidal biospararenite, and 9) algal biolithite facies. These facies contain textural features indicative of both low- and high-energy conditions. The biolithite facies contains thin, laminated dolomite with presumed algal laminations and mudcracks which were interpreted as supratidal in origin.

Together the carbonate facies identified by Sbeta (1970) are indicative of environments ranging from subtidal to supratidal and represent the kinds of limestone usually associated with shallow-water, carbonate-bank settings. Curiously, Sbeta made little mention of any coral or spongiomorph fossils, although he listed brachiopods, mollusks, and crinoids as abundant. Coral fragments were only briefly mentioned as "traces" and "fragments" in the biomicarenite facies. It is thus unclear how the coral zone of Smith (1927) fits into the facies studied by Sbeta (1970).

Fossils.—Only a few of the corals identified in the Hosselkus by Smith (1927) were found during field work in the Lake Shasta area. Corals and spongiomorphs described by Smith (1927, p. 7) include: *Spongiomorpha dendriformis* Smith, *S.* cf. *S. gibbosa* Frech, *S. tenuis* Smith, *Stromatomorpha californica* Smith, *"Thecosmilia"* cf. *"T." fenestrata* Reuss, *"Montlivaltia" norica* Frech, *Palaeastraea descussata* (Reuss), *Elysastraea vancouverensis* (Clapp and Shimer), *E. profunda* Reuss, *Margarastraea eucystis* (Frech), *Actinastraea* cf. *A. juvavica* (Frech), *A. shastensis* (Smith), *Thamnasteria rectilamellosa* var. *minor* Frech, *T. rectilamellosa* Frech, *Palaeastraea grandissima* (Frech).

The taxonomic positions of most of the corals described by Smith have been discussed in detail by Squires (1956). The fauna listed above is almost identical to that from the Luning Formation at Mina (Table 1). Little is known about the distribution of the coral and spongiomorph biota within the facies of the Hosselkus.

Discussion.—Although the present investigation at the Lake Shasta area was not totally successful in documenting the alleged "coral reefs" of Smith (1927), the one outcrop investigated did not reveal any true coral reef structures. It appears that the corals at the locality investigated are more like those at New Pass and may be best referred to as thin, coral biostromes within a carbonate bank setting.

Judging from the types of carbonate facies in the Hosselkus, the corals may have lived in shallow-water environments at depths comparable to those in the Bahamas where similar types of carbonate sediment are now forming. Further discussion must await more successful work in the area.

Age.—The age of the corals and the "coral zone" in the Hosselkus is early Norian. The Hosselkus section described by Smith (1927, p. 2) was later discussed by Silberling (1956, p. 1152; 1959, p. 21) and by Silberling and Tozer (1968, p. 42-43). The corals occur well above the upper Karnian Welleri zone characterized by the ammonite *Tropites welleri* and associated fauna, and below the upper Norian Seussi zone containing *Rhabdoceras suessi* and *Monotis subcircularis*. Silberling (pers. commun., May, 1976) agrees with the view that Smith's coral zone is most likely earliest Norian.

WALLOWA MOUNTAINS, OREGON

Setting and stratigraphy.—In the Wallowa Mountains of northeastern Oregon, Triassic coral reefs have been reported in the Martin Bridge Formation by Smith (1912, 1927). The Wallowa Mountains are a northeastern extension of the Blue Mountains, and are divisible into northern and southern regions. Relationships between these two regions have been obscured largely by the intrusion of the late Mesozoic Wallowa Batholith. Limestone referred to as the Martin Bridge is present in both areas. The geology of the northern Wallowas has been presented by Smith and Allen (1941), while Ross (1938) has outlined the geology of the southern portion.

Smith (1912, p. 95) presented a measured section on Eagle Creek in the southern Wallowas. He described 12.2 m of "thin-bedded limestone with banks of corals . . ." which he regarded as a coral reef in the Martin Bridge Formation. Later Smith (1927) described the corals from this reef and assigned them to the lower Norian coral zone, also recognized in the Lake Shasta area. Few details concerning the nature of the "coral reef" were given.

The Martin Bridge Formation was named and described in the southern Wallowa Mountains by Ross (1938) for interbedded massive and thin-bedded limestone and calcareous shale on the Eagle River at Martin Bridge, where the thickness is estimated to be 460 m. H. J. Prostka and R. L. Bateman mapped the area in the southern Wallowas where Smith described the coral reefs (Geologic Map of the Sparta Qudarangle, Oregon Dept. Geol. and Miner. Ind., Geol. Map ser. 1, 1962). Prostka (1963) described the Martin Bridge as con-

glomeratic and coralline limestone interbedded with calcareous, carbonaceous, and ferruginous shale. The Martin Bridge is overlain by laminated argillite, mudstone, graywacke, and chert of the Hurwall Formation. This unit is 1,250 m thick and contains sedimentary features indicative of turbidite deposition. The Martin Bridge is underlain by the "lower Sedimentary Series (Clover Creek Formation), a thick succession of volcaniclastic rocks, breccia, sandstone, and siltstone.

The northern Wallowas were studied by Nolf (1966), who recognized units similar to those in the southern Wallowas. In the northern Wallowas the Martin Bridge is recognized and is between 340 and 370 m thick. It is overlain by the Hurwall Formation and underlain by the Clover Creek Formation. It should be pointed out, however, that there are differing opinions on the stratigraphy and correlation of the rocks in the northern and southern Wallowas. The Martin Bridge and other Triassic units defined in the southern Wallowas have also been recognized in the north by Nolf (1966). However, workers at the U.S.G.S. and the University of Washington do not agree and interpret the units to the north as individual, stratigraphically unrelated thrust sheets (Bruce Nolf, pers. commun., August, 1975). Therefore the projection of the name Martin Bridge to the north is questionable.

The Martin Bridge is divisible into three members: BC Creek, Hurricane Creek, and Scotch Creek members. According to Nolf's work, the Hurricane Creek is considered to be a massive northwest-trending reef. Nolf also regards the laterally equivalent BC Creek as a back-reef facies. Both members are overlain by the Scotch Creek Member, which contains coarse-grained fossiliferous calcarenites. Not a single fossil has been collected from the reef facies as it is a structureless, totally recrystallized limestone mass, 93 to 171 m thick. Its interpretation as a reef is based solely on its position as a barrier relative to adjacent facies. The laterally adjacent BC Creek Member is a thin-bedded, fossiliferous, fine-grained limestone that contains a variety of invertebrate fossils including corals and spongiomorphs.

During the summers of 1975 and 1976, field work was conducted in both the southern and northern Wallowas. In the southern Wallowas, Smith's coral locality along Eagle Creek in the Martin Bridge Formation was investigated. The measured section is given in Appendix C. In the northern Wallowas, the Martin Bridge was examined at Hurricane Creek near the town of Enterprise and at the nearby Black Marble Quarry. The latter locality is somewhat problematical. Although generally regarded as part of the Martin Bridge, the lithologies at this quarry are quite typical, consisting of black, carbonaceous, medium- to thin-bedded limestone. Corals and spongiomorphs are abundant (Fig. 8E-G).

Nolf (1966) believed that the Black Marble Quarry limestone is a huge allochthonous block within the Hurwall Formation, which during the Triassic was displaced by gravity, sliding from a shallow shelf environment into deeper water environments of the Hurwall. If this were true the black limestone of the quarry is comparable in origin to the Cipitkalk limestone blocks of the Triassic Italian Dolomite Alps. Results of current field work in the Wallowas and my own views are presented in the discussion at the end of this chapter.

Sections were measured at three localities in Oregon: the Martin Bridge Formation in the southern Wallowas, the Martin Bridge of the northern Wallowas, and at the Black Marble Quarry of the northern Wallowas. The described section in the southern Wallowas is given in Appendix C.

Hurricane Creek Locality

Martin Bridge Formation, northern Wallowas section measured on the west side of Hurricane Creek just south of Little Granite Creek. SW¼ sec. 3 and NW ¼ sec. 10, T. 3 S., R. 44 E.

A section about 240 m thick was examined along the steep bluffs bordering Hurricane Creek. At this locality approximately 150 m of gray to white, massively bedded marble was measured. This is the Hurricane Creek Member of the Martin Bridge. Few signs of bedding are present, and the unit is so extensively recrystallized that almost all signs of primary structures are obliterated. Parts of the unit exhibit thin laminations, each lamina being a centimeter or more in thickness. These laminations appear to increase toward the top of the unit.

The contact with the overlying unit is gradational. The marble lithology passes upward in section into fossiliferous, thin- to medium-bedded limestone of the Scotch Creek Member. Some beds in this unit consist of bivalve coquinas containing corals and spongiomorph fragments, brachiopods, gastropods, and echinoderms. Large lithoclasts are present. Most of the corals are not identifiable and appear as small broken fragments probably of incrusting and platy types of corals. At other areas along Hurricane Creek, the Scotch Creek Member contains thamnasteriid corals, branching spongiomorphs, the bivalve *Septocardia,* and aulacoceratid cephalapods.

Black Marble Quarry Locality

Martin Bridge Formation, northern Wallowas, near Enterprise, Oregon. Sec. 19, T. 2 S., R. 44 E.

This quarry is located on the mountainside near Enterprise at at 5,800 foot topographic contour interval. It contains a thick sequence of massively bedded, black limestone, which is quarried here (Fig. 8D). The quarry is 80 to 100 m high and has a well-exposed vertical face. It contains two high angle faults and some minor folding, and beds generally dip 10° to the southwest. Due to structural complications, the thickness is difficult to measure but at least 125 m of limestone is present. Because of poor exposure and dense vegetation in surrounding areas, the limestone cannot be traced laterally from the quarry site. However it is at the same stratigraphic level as the Hurwall Formation and is overlain by this unit. Thus it appears to lie within or at the base of this formation.

Limestone dominates almost entirely in the quarry but very thin shale partings occur between some beds. The black limestone in the quarry is highly carbonaceous with a fetid odor when

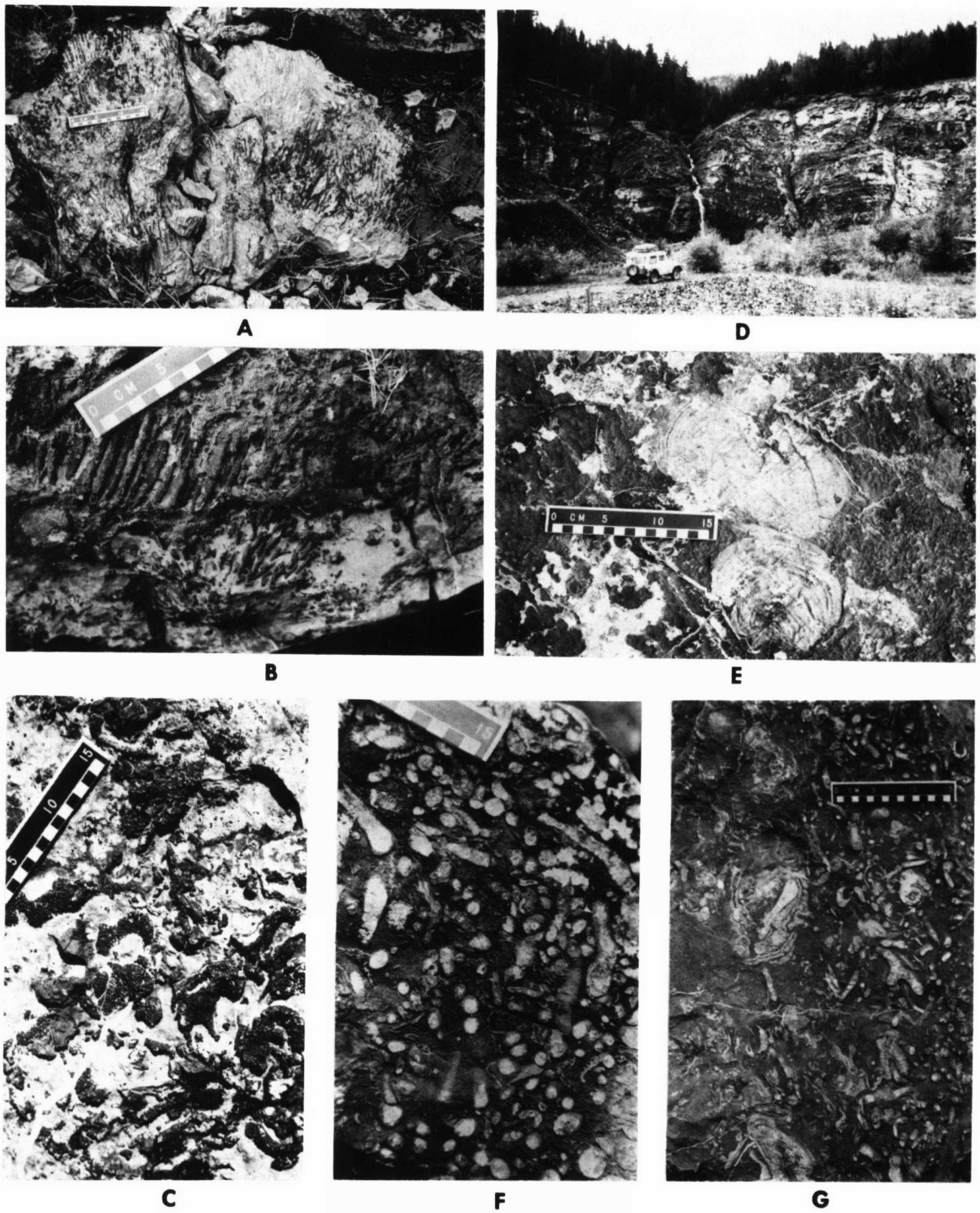

FIG. 8. Coral buildups in Oregon and Vancouver Island.———A. Mass of *"Thecosmilia" suttonensis* at Vancouver Island. Note drape of bed over coral colony.———B. Small colony of *"Thecosmilia" dawsoni* (below) grown over by larger *"T." suttonensis* colony (above), Vancouver Island.———C. Numerous thin incrusting corals, representing several species of *Elysastraea,* on bedding plane, Vancouver Island.———D. View of the Black Marble Quarry, Oregon. Several high angle faults are visible.———E. Several *in situ* headlike colonies of the spongiomorph *Heptastylis* on vertical face of limestone bed. Black Marble Quarry, Oregon.———F. Weathered block of limestone with branching spongiomorphs in fine-grained, black limestone. Black Marble Quarry, Oregon.———G. Large block of limestone that has fallen from top of quarry, showing incrusting corals succeeded by numerous branching spongiomorphs. Stratigraphic orientation is up to the right of photograph. Black Marble Quarry, Oregon. Scale in centimeters.

broken. It contains abundant branching and incrusting spongiomorphs, corals, calcisponges, and bivalves. Some of the *in situ* branching spongiomorphs and corals form local patchlike concentrations in irregular beds up to a meter in thickness; generally, no greater thickness of framework is present (Fig. 8F). A variety of bivalves are distributed through the limestone. Most of the fossils are recrystallized and appear white against a black, fine-grained limestone matrix.

Lithofacies.—Thin sections from several sampled intervals in the Black Marble Quarry were analyzed petrographically. All of the carbonates examined contained fine-grained (micrite) matrices. Three facies types are present: 1) mudstone-fossil wackestone, 2) coelenterate-mollusk packstone, and 3) coelenterate framestone.

The mudstone-wackestone facies is very extensive in the quarry and alternates with the other facies types. It is characterized by sparsely fossiliferous micrite containing occasional foraminifers, bivalve shells, and fine spicular material. The second facies is a packstone characterized by both coral and spongiomorph fragments in a fine-grained micrite matrix. Unidentifiable spinose bivalves are also present (Pl. 8, fig. 14). In this facies, few of the large coelenterates are in life position. The third facies is characterized by either branching *Spongiomorpha* or branching *Thamnasteria* (Pl. 10, fig. 3), which are *in situ* and form a solid framework similar to that usually associated with reef structures.

Generally the fossil constituents in the three lithofacies are whole and unabraded, indicating little postmortem transportation. In the framework facies, the corals and other fossils are in growth position, clearly indicating that the beds are right side up. The micritic matrix and unabraded fossil constituents indicate that the rocks were deposited in a quiet-water environment. Dark, presumably organic matter is abundant and finely distributed through all of the fetid limestone, and pyrite is also common. This suggests euxinic or reducing conditions in the sediment during original deposition of the limestone. Algae are completely absent in any of the facies.

Thin sections examined from other coralliferous limestones at the Eagle Creek and Hurricane Creek localities contained intraclastic and fossil grainstones and packstones as well as oolites. These carbonates are indicative of high-energy, shallower water environments. The limestones at Eagle Creek contain abundant rounded intraclasts and carbonate breccias with clasts up to 2 cm in diameter. Also present at this locality are well-sorted, rounded grainstones containing algae-coated grains, pellets, and oolites up to 1 mm in diameter. Many of these lithofacies are identical to facies types in the Hosselkus Limestone as described by Sbeta (1970). The limestones examined from the Hurricane Creek locality were too recrystallized to yield much information, but samples from the overlying Scotch Creek Member revealed bioclastic, intraclastic, and ruditic grainstone textures similar to those found at Eagle Creek. As pointed out by Nolf (1966), some beds in the Scotch Creek Member contain these types of textures in association with cross-bedding. Vallier (1974) also noted similar textures in the Martin Bridge of the Snake River Canyon area 48 km east, near the Oregon-Idaho border.

Fossils.—A diverse association of invertebrates is present in the Wallowa Mountains localities, including a variety of corals and spongiomorphs (Table 4). Only a small amount of fossil material was collected from the Hurricane Creek locality, most of which is poorly preserved and difficult to identify. No reefoid structures were observed. A much greater variety of corals was obtained from the Eagle Creek locality in the southern Wallowas. Here large branching *Spongiomorpha dendriformis* and *S. tenuis* (Pl. 6, fig. 2) are conspicuous and are frequently associated with flat massive and platy corals, as well as branching *Thamnasteria* colonies. Some of the coral and spongiomorph species at Mina, Nevada, and Lake Shasta, California, occur at Eagle Creek; but many other species are absent.

Additional coelenterates not collected in this study but mentioned at the Eagle Creek locality by Smith (1927) are *Stylophyllopsis zitteli* Frech and *S. mojsvari* Frech. Smith (1912, p. 95) listed *Heterastridium conglobatum* Reuss from Eagle Creek. However, this hydrozoan was not mentioned in his 1927 publication. It appears that some specimens described by Smith (1927) as *Heptastylis oregonensis* may have originally been misidentified as *Heterastridium*. Only one poorly preserved example of *H. oregonensis* was found in this study. Recognized in this study for the first time at Eagle Creek is *Actinastraea* cf. *A. juvavica* (Frech). A single specimen of large branching *Elysastraea* cf. *E. profunda* (Reuss) was collected. This branching type of growth is unknown in any other specimen referred to this genus. These species are typical of other coral localities of early Norian age.

The corals and spongiomorphs of the Black Marble Quarry contain some genera and species unknown in the southern Wallowas or anywhere else in the study. Many of the corals and sponges are similar to faunas of the St. Cassiano beds (Karnian) of Italy. Bryozoan-like incrusting organisms, common in the quarry, are assigned to the genus *Heptastylis,* a spongiomorph (Pl. 6, fig. 6).

At the Black Marble Quarry, spongiomorphs are conspicuous and rival the corals in abundance. The branching spongiomorph *Spongiomorpha dendriformis* reaches 15 to 30 cm in height and appears to dominate in most beds. Specimens of branching *S. ramosa* (Pl. 6, fig. 3) are common. Many spongiomorph beds are composed largely of the branches of *S. ramosa* (Fig. 8F). Other beds are dominated by branching thamnasteriid corals. Most of the corals are flat and incrust-

TABLE 4.—*Fossils from the Martin Bridge Formation, Wallowa Mountains, Oregon.*

Fossil Group	Eagle Creek Locality	Hurricane Creek Locality	Black Marble Quarry
Foraminifera			uniserial forms (cf. *Nodosaria*) indet. ?endothyrids indet. tubular, planispiral forms
Porifera	indet. pharetronid sponges	*Waagenella* sp. *?Zardinia* sp. indet. calcisponges	*Amblysiphonella* cf. *A. timorica* Vinassa *Ascosymplegma* sp. *Corynella* sp. *Cryptocoelia* sp. *Waagenella* cf. *W. utriculus* (Vinassa)
Coelenterata			
Hydrozoa	*Heptastylis aquilae* Smith *H. oregonensis* Smith *Spongiomorpha* cf. *S. dendriformis* (Smith) *S. tenuis* (Smith)	*Spongiomorpha* cf. *S. tenuis* (Smith)	*Heptastylis* cf. *H. aquilae* Smith *Spongiomorpha* cf. *S. acyclica* Frech *S.* cf. *S. dendriformis* (Smith)
Scleractinia	*Actinastraea* cf. *A. juvavica* *Astraeomorpha confusa* (Winkler) *Elysastraea* cf. *E. profunda* (Reuss) *"Montlivaltia" norica* Frech *"Thecosmilia"* sp. 1 *"Thecosmilia"* sp. 2	*Actinastraea* sp. *Elysastraea profunda* (Reuss) *Thamnasteria* sp. *"Thecosmilia"* sp.	*"Montlivaltia"* sp. *Oppelismilia* sp. *Palaeastraea* cf. *P. decipiens* (Laube) *Stylophyllum* sp. *"Thecosmilia"* cf. *"T." confluens* Munster *Thamnasteria* sp. *T.* cf. *T. borealis* Smith
Brachiopoda	indet. spiriferids indet. terebratulids		
Mollusca			
Bivalvia	indet. large nuculoids indet. spinose types	*Septocardia* sp. indet. mytilid indet. pectinid	indet. halobiids indet. thick spinose forms indet. thin-shelled forms
Gastropoda	*"Purpuroidea"* sp. indet. naticid indet. trochoid types		indet. trochid forms
Cephalopoda		indet. aulacoceratid	*Tropites* sp.
Echinodermata	cidarid echinoid spines and plates indet. crinoid columnals	cnidarid echinoid species	crinoid columnals echinoid spines and plates
Incertae Sedis	incrusting "worm tubes"		

ing or appear as small semi-domate heads. Almost all fossils are recrystallized but details of the coralla appear on weathered slabs. Numerous calcisponges, such as *Waagenella* (5 to 10 cm long) and large *Ascosymplegma* (30 to 60 cm), are frequently associated with the corals and spongiomorphs (Pl. 8, figs. 1, 2). Gastropods and spinose bivalves (Pl. 8, fig. 14) are also commonly associated with the coelenterates and sponges.

Discussion.—None of the three areas investigated revealed any signs of true reef framework or reef talus deposits. Coral-spongiomorph faunas from the three localities show some differences in composition, especially that of the Black Marble Quarry. The limestone referred to as the Martin Bridge in both the northern and southern Wallowas is extensively recrystallized, posing problems for identification of fossils. Few of the limestone sequences appear to contain any totally silicified fossils.

Smith's so-called "reef" on Eagle Creek is best referred to as coralliferous limestone. To judge from the textures of the associated carbonates, it probably devel-

oped in a shallow-water carbonate bank setting, perhaps similar to rocks in the Hosselkus Limestone at the Lake Shasta region. The assignment by Nolf (1966) of a reef in the Martin Bridge of the Northern Wallowa Mountains is difficult to assess in that no fossils have yet been found. However, the facies relationship of these rocks within the formation and the presence of abundant reef-building organisms in other shallow-water members supports the possibility of reef development. Vallier (1974) also reported a "reef facies" in the recrystallized Martin Bridge of the Snake River Canyon.

In the northern Wallowas, corals are not restricted to the Martin Bridge but occur also in the overlying Hurwall Formation and underlying Clover Creek Formation (Nolf, 1966). Unlike rocks of the Martin Bridge, the Hurwall rocks contain sedimentary structures indicative of deeper water, turbidite deposition. Ammonites date the Hurwall as Late Triassic to Jurassic. Although I did not find corals in this unit, Nolf (1966) reported reworked corals, spongiomorphs, and other benthonic invertebrates within limestone clasts of the middle Hurwall limestone.

The Black Marble Quarry was interpreted by Nolf (1966) as a block of shallow-water limestone displaced into deeper water environments. If so, the rocks exposed at the quarry represent one of the largest exotic blocks ever observed in the Hurwall. Thick breccia beds and allochthonous blocks over 90 m long are known at horizons in the middle of the Hurwall, and some of these contain benthonic organisms including corals. The textural features of the carbonaceous limestone in the Black Marble Quarry and the lack of algae indicate that these rocks may have been deposited in quiet and deeper water environments, perhaps characterized by euxinic sediments.

All of the coral faunas in the Martin Bridge (Table 4) were also collected in California and Nevada, but the coral fauna of the Black Marble Quarry contains many taxa unknown from any other areas in this study.

Age.—The coral faunas in the Wallowas may be of different ages as indicated by this study. The Martin Bridge coral fauna in the southern Wallowas described by Smith (1912, 1927) appears to be early Norian on the basis of the occurrence of *Halobia halorica* and *H. dilatata* in the shale above the coral beds.

The coral faunas of the Martin Bridge in the northern Wallowas are placed in the earliest Norian on the basis of the presence of *Tropiceltites* cf. *T. columbianus* (Silberling and Tozer, 1968, p. 41), which is indicative of the Kerri Zone.

The Black Marble Quarry coral fauna is assigned a late Karnian (Dilleri Zone) age on the basis of the occurrence of *Tropites dilleri* and other ammonites (Nolf, 1966). Muller (in Smith and Allen, 1941, p. 59) listed the ammonites from this quarry and stated that the ammonite fauna is almost identical to that of the Hosselkus in the Lake Shasta region.

It thus appears that the coral fauna of the Black Marble Quarry is somewhat older than the other coral faunas. The sponge fauna collected there (Table 4) is unique and the beds contain both sponges and corals known from the Karnian of Italy. The presence of a Karnian fauna at a stratigraphic position presumably above rocks dated as Norian was used by Nolf to support the idea that the quarry was an allochthonous block. Corals and spongiomorphs of the Black Marble Quarry are similar to those reported by Nolf (1966) in the Karnian Clover Creek Formation. This unit underlies the Martin Bridge and contains considerable amounts of volcanics and minor carbonates. The Clover Creek was not investigated by me, but similarities between its fauna and those of the Black Marble Quarry suggest possible correlations.

LEWISTON, IDAHO

Setting and stratigraphy.—Upper Triassic limestone containing corals has been reported by Squires (1956) from an isolated inlier of limestone that appears to be a roof pendant of the Idaho Batholith. The locality in which the corals occur is in a quarry near the town of Lewiston in western Idaho on the Lapwai Indian Reservation. The fossiliferous limestone at the quarry poses stratigraphic problems because it cannot be physically correlated with known rocks of Triassic age. Squires (1956) described the corals and referred them to the "Seven Devils Formation" (Seven Devils Volcanics) on the basis of work done by Cooper (1942). Since no geologic mapping has been done in the area, little is known about the stratigraphic position or correlation of the limestone at this quarry.

I investigated this locality during field work in 1976. The quarry contains about 150 m of massive-bedded, partly recrystallized limestone. The total sequence could not be measured because much of the vertical quarry face is inaccessible. Corals occur commonly in beds from 1 to 10 m thick. Some of these beds clearly thicken and thin along the quarry wall and most contain a framework structure of branching and platy corals within the limestone. Broken and abraded coral fragments are common in most beds. The coral beds alternate with sparsely fossiliferous, noncoralline beds or beds containing abundant mollusks. Unfortunately many of the limestone beds have been metamorphosed and totally recrystallized. Many of the unrecrystallized, fossiliferous beds contain silicified fossils, but these are only apparent on weathered surfaces.

The best silicified material occurs along the top of the quarry. A representative section containing a few of the coral beds is given in Appendix D. In addition to

specimens collected at this locality, an excellent collection of silicified corals was obtained from the U. S. National Museum. Some of these specimens are illustrated in the plates and the fauna is listed in Table 5.

TABLE 5.—*Fossils from Lewiston, Idaho.*

PORIFERA
?Corynella sp.
Precorynella sp.
Thaumastocoelia sp.
COELENTERATA
?Hydrozoa
?Heptastylis (cf. *Tubulitrypa maculata* Flügel)
?H. sp. (cf. *Zlambachella alpina* Flügel)
Scleractinia
Actinastraea idahoensis (Squires)
A. schafhaeutli (Winkler)
Astraeomorpha cuneata Squires
Coccophyllum acanthophorum Frech
Elysastraea profunda (Reuss)
E. cf. *E. vancouverensis* (Clapp and Shimer)
"Montlivaltia" norica Frech
Oppelismilia cf. *O. zitteli* (Frech)
Stylophyllum paradoxum Frech
Thamnasteria smithi Squires
"Thecosmilia" cf. *"T." dawsoni* (Clapp and Shimer
"T." cf. *"T." suttonensis* (Clapp and Shimer)
BRACHIOPODA
Spondylospira sp.
indet. spiriferids
MOLLUSCA
Bivalvia
Trigonia (*Kumatrigonia*) sp.
indet. myophorid
indet. nuculoid forms
Gastropoda
indet. high spired forms
ECHINODERMATA
Echinoidea
Levicidaris sp.
Triadocidaris sp.
Zardinechinus sp.
INCERTAE SEDIS
wormlike tubes

The geology and stratigraphy of the Seven Devils region, Idaho, was given by Cook (1954). Cook described a thick sequence of Triassic shale and limestone that unconformably overlies the Seven Devils Volcanics. These Triassic rocks were named the Lucile Series by Wagner (1945, p. 3), who described three members near Lucile, Idaho. Correlations between the Lucile Series and the Martin Bridge Formation were suggested, based on similarities in lithography.

Vallier (1974) mapped the Seven Devils Group (Seven Devils Volcanics) and overlying rocks in the Snake River Canyon, along the Oregon-Idaho border, about 40 km west of the Lewiston locality. In this locality the Martin Bridge Formation is assigned to rocks above the Seven Devils and below the Jurassic. Vallier suggested correlations of the Martin Bridge with Triassic rocks of the Lucile area.

Lithofacies.—Because many of the limestones are extensively recrystallized, they yield little information on original textures and the nature of the rock fabric. The less recrystallized beds consist dominantly of packstone and grainstone rock types with abundant broken and abraded coral and molluskan debris. Small lithoclasts, pellets, and algal-coated grains are common but oolitic textures were observed.

Other carbonate rocks contain whole and abraded recrystallized corals (framestones). Some of these are in growth positions, and the interstitial areas between the corals contain abundant abraded fossil debris. Both branching and incrusting types are present. The general nature of the rock types from the less recrystallized beds suggests typical shallow-water carbonate deposition and growth of framework-building organisms.

Fossils.—A number of coelenterates and sponges were identified from the Lewiston locality (Table 5). The sponges (Pl. 8, figs. 3, 4) are small and inconspicuous relative to the corals. The most abundant corals are *"Thecosmilia"* and *"Montlivaltia"* (Pl. 2, figs. 8-10). A large part of the coral fauna does not occur in any of the previously described localities, including *Actinastraea idahoensis* (Pl. 1, fig. 1), *A. schafhaeutli* (Pl. 1, fig. 2), *A. ohmanni* (Pl. 1, fig. 3), *Astraeomorpha cuneata, Stylophyllum paradoxum, Oppelismilia zitteli,* and *Coccophyllum acanthophorum.* With the exception of *A. idahoensis,* these are species known from the Zlambach beds (Norian-Rhaetian) of Fischerwiese, Austria.

Coccophyllum acanthophorum (Pl. 2, fig. 6) is a common, thin, incrusting coral. *Actinastraea* forms thicker, flat, platy colonies. *Elysastraea profunda* (Pl. 3, fig. 8) is present but not abundant. It assumes a low, incrusting growth, producing slightly convex heads only a few centimeters in diameter and never as large as observed at other localities. *Thamnasteria* is present and represented by two species (Table 5). Both occur as small, nodular or incrusting colonies 1 to 5 cm in diameter (Pl. 1, fig. 10) which never assume the arborescent or massive platelike forms so typical of other species.

Small (1 to 2 cm long) bifurcating and globular, bryozoanlike hydrozoans of the genus *?Heptastylis* are present. These may be the bryozoans referred to by Squires (1956). They resemble *Zlambachella alpina* and *Tubulitrypa maculata* (Pl. 4, figs. 6, 8, 9) from the Zlambach beds of Austria, both described by Flügel (1961) as Bryozoa. R. S. Boardman (pers. commun., March, 1977) is of the opinion that these are coelenterates and definitely not bryozoans. On the other hand, Roger J. Cuffey (pers. commun., August, 1977) believes that these specimens may be sclerosponges.

Besides the corals, mollusks are abundant. Both

gastropods and bivalves are present, but, due to poor preservation, few have been identified. Myophorid bivalves are abundant (Pl. 9, figs. 4, 5), and a trigonid, ?*Trigonia* (*Kumatrigonia*) sp., is present (Pl. 9, figs. 2, 3). Spiriferid brachiopods are present including *Spondylospira*. Many of the corals are incrusted by fine tubes probably secreted by worms.

Echinoid material (spines and plates) is present in association with the corals. Preliminary identifications were made by Porter M. Kier (Table 5), who reported that they are entirely new and very similar to species from the St. Cassiano Beds of Italy (pers. commun., February, 1978).

Discussion.—Although a massive reef structure is not present at the Lewiston locality, many of these beds display a framework structure produced by corals. Relative to the corals the bryozoanlike spongiomorphs appear to play a rather minor role. However, spongiomorphs may be absent altogether if these bryozoanlike fossils are actually sclerosponges. Cuif (1974b) has described some of the oldest known sclerosponges from the Upper Triassic of Italy, which bear some resemblance to the specimens from Idaho.

Squires (1956) did not investigate the actual outcrop from which he described the corals. His statement (1956, p. 7) that the locality probably represents a bank or shoal environment appears to be essentially correct. My investigation suggests that the coral and mollusk faunas probably developed on a shallow carbonate bank as local, thin, patchlike buildups. Wave action is suggested in some parts of the sequence by the presence of abundant broken and abraded coral fragments. A similar conclusion was reached by Squires (1956), based on coral growth forms, which suggested frequent overturning of the coralla.

Age.—The correlation of the limestone at the quarry is not clear. The gastropods (Haas, 1953, p. 304, 310) suggest a Norian-Rhaetian age, the brachiopods (Cooper, 1942, p. 232) and the corals and spongiomorphs, a Norian to Rhaetian age. The difference from the coral fauna of the Wallowa Mountains could indicate that the Lewiston fauna is younger, perhaps of latest Norian age. No diagnostic ammonites have been discovered, and the age of the known fauna is equivocal.

I have chosen tentatively to regard the Lewiston locality as Upper Norian. The limestone of the quarry may correlate with the Martin Bridge of Nolf (1966) and Vallier (1974). The Martin Bridge in Oregon, however, is generally thought to be no younger than early Norian (Kerri Zone) on the basis of ammonite occurrences. If the limestone at the Lewiston locality is late Norian in age, this would mean that its deposition was roughly contemporaneous with that of the Hurwall Formation in Oregon.

VANCOUVER ISLAND, BRITISH COLUMBIA

Setting and stratigraphy.—Triassic coral reefs were reported from southern Vancouver Island, British Columbia, on the shore of Lake Cowichan by Clapp and Shimer (1911). These authors referred to the coral-bearing limestone as the Sutton Formation. The "coral reefs" occur in limestone lenses that are intercalated with volcaniclastics and lava flows of the Vancouver Group. At least two coral beds were reported from this locality. Not only corals, but brachiopods, bivalves, and ammonites were described from associated beds. Shimer (1926) later reported a second Triassic coral locality in British Columbia.

Since these early reports, Late Triassic coral faunas have become known in various parts of Vancouver Island (Jeletzky, 1950, 1970; Muller, Northcote, & Carlisle, 1974). Triassic corals have also been reported on the mainland of British Columbia as well as in the southern Yukon. Most of these are considered to be Late Triassic (late Norian), and they all occur within the volcanic eugeosynclinal portion of the western Canadian Cordillera. Most of the corals are described as poorly preserved. A summary of the corals and associated benthonic faunas was presented by Tozer (1970). The locality in the Sutton Formation at Lake Cowichan was chosen for study because it is one of the best known localities, it is easily accessible, and it contains abundant, well-preserved fossils.

The stratigraphy of the Vancouver Group and the Sutton Formation was presented by Fyles (1955). The limestone of the Sutton Formation occurs within a thick sequence of basalt flows, shales, and volcaniclastic rocks. According to Fyles, the limestone is about 156 m thick and occurs near the top of the Vancouver volcanic sequence. The limestone of the Sutton grades laterally into volcaniclastic deposits.

During the summers of 1975 and 1976, I investigated the locality of Clapp and Shimer (1911). The described section is given in Appendix E. At this locality two reefoid lenses, 1.8 and 2.4 m thick, occur in the limestone sequences. These thin beds contain a diverse association of corals, and each is overlain by bivalve coquina beds (Pl. 9, fig. 6). The Sutton Limestone was also examined at other nearby areas but nowhere was it very fossiliferous. Although fossil corals occur at other outcrops, they do not contain a reefoid framework structure like that exposed in the measured section on Lake Cowichan.

The Sutton Formation of southern Vancouver Island has been correlated with the Parsons Bay Formation of the northern part of the island (Jeletzky, 1970). The Parsons Bay Formation occurs at the top of the Vancouver Group volcanics and, like the Sutton of southern Vancouver Island, contains similar thin reefoid limestones with bivalve-coral associations. Muller, North-

cote, and Carlisle (1974) assigned the Sutton to the category of member within the Parsons Bay Formation of northern Vancouver Island.

Lithofacies.—The limestone of the Lake Cowichan locality was examined in thin sections. Recrystallization has affected some of the beds but several facies types are easily distinguishable. These are mollusk grainstone facies, mollusk packstone facies, coral wackestone facies, and coral framestone-bindstone facies. Generally calm-water conditions are indicated for the corals.

The mollusk grainstone facies characterizes much of the measured section (units 1, 3, 5, 6, 8, and 10). This facies is a skeletal, intraclastic, spar-cemented carbonate rock with abundant abraded bivalve shells and rounded clasts. Many of the clasts are basaltic and andesitic rock fragments, while other clasts are limestone and broken corals. Echinoderm spines and plates are common and foraminiferal tests are also present. At the top of unit 10 this facies consists of well-sorted, finely laminated shell debris. This is present overlying both of the coral beds. The mollusk packstone facies (Pl. 10, fig. 1) occurs in units 7, 8, and 10, usually associated with the grainstone facies. It differs from this facies only by containing a micritic matrix and less sorting of the allochems.

The coral wackestone facies consists of scattered coral fragments within a fine-grained, micritic matrix. Large volcanic rock fragments are present. This facies characterizes intervals in both of the coral beds. Also present in both coral beds is the coral framestone-bindstone facies (Pl. 10, fig. 2). This facies contains either large branching or thin incrusting corals. Some brachiopods, gastropods, and pelecypods occur in this facies and it appears to grade laterally into the mollusk packstone facies.

The lithofacies associated with the coral beds contains evidence of shallow-water, high-energy conditions. Commonly, broken and abraded molluskan debris is evident. The facies seems generally typical of the shallow-water environment except that neither oolites, oncolites, nor algae were observed, perhaps indicating that warm-water conditions were not present. The abundant subrounded and angular volcanic rock fragments in some facies were undoubtedly derived from bordering volcanic highlands. Organic material in unit 6 is probably carbonized wood. Fyles (1955, p. 24) reported large fossil trunks of coniferous trees from these beds.

The alleged coral reefs at Lake Cowichan are actually only thin patchlike buildups that probably attained relief of only a meter or less above the surrounding substrate. They were abruptly terminated and subsequently repopulated by low-lying banks of bivalves. This is quite similar to relationships at Mina, Nevada, and a similar type of biotic zonation is present in the coral beds, with large *"Thecosmilia"* clusters characterizing the top of bed 9 (Figs. 8A, B).

Fossils.—The invertebrates collected from the Sutton have yielded an excellent silicified fauna (Table 6). A wide variety of corals is present, but no spongiomorphs were found. The corals include large branching colonies of *Astraeomorpha cuneata* (Pl. 2, fig. 4) and several species of *Elysastraea*. *Elysastraea profunda* is abundant and occurs as thin incrusting colonies up to 20

TABLE 6.—*Fossils of the Sutton Limestone, Vancouver Island, British Columbia.*

FORAMINIFERA
?Spiroplectammina sp.
?endothyrid types
biserial textularids
PORIFERA
?Euepirrhysia sp.
Thaumastocoelia sp.
indet. spicules
COELENTERATA
Scleractinia
Actinastraea cf. *A. idahoensis* (Squires)
A. cf. *A. ohmanni* (Frech)
A. schafhaeutli (Winkler)
Astraeomorpha cuneata (Squires)
A. confusa var. *minor* (Frech)
Coccophyllum acanthophorum Frech
Elysastraea cf. *E. major* (Frech)
E. profunda (Reuss)
E. vancouverensis (Clapp and Shimer)
Margarastraea sp.
"Montlivaltia" cf. *"M." norica* Frech
Thamnasteria smithi Squires
"Thecosmilia" dawsoni (Clapp and Shimer)
"T." suttonensis (Clapp and Shimer)
BRACHIOPODA
"Terebratula" suttonensis (Clapp and Shimer)
MOLLUSCA
Bivalvia
Cardinia sp.
Costatoria sp.
Minetrigonia suttonensis (Clapp and Shimer)
?Myophoria sp.
Ostrea sp.
Pectinids
Septocardia sp.
Trigonia (*Kumatrigonia*) sp.
indet.? cardiaceans
Gastropoda
indet. small trochoid form
indet. small turritellid form
Cephalopoda
aulacoceratids (gen. et species indet.)
ECHINODERMATA
Echinoidea
Levicidaris sp.
Triadocidaris sp.
INCERTAE SEDIS
indet. small incrusting "worm" tubes
small spicules

cm in length (Pl. 3, fig. 6). *E. vancouverensis* is an abundant platy coral (Pl. 4, fig. 3). *Elysastraea* cf. *E. major* is a rare coral identified for the first time from the Sutton. It was reported from Idaho by Squires (1956).

The fauna of the Sutton contains corals remarkably similar to those from Idaho (see Table 5). Of the 15 coral species collected from Vancouver Island (Table 6), 11 are known from Idaho. Eight of these are not known in North America outside of Idaho and Vancouver Island. *Coccophyllum acanthophorum* from Idaho is an incrusting coral, but it occurs at Vancouver Island as a twisted, branching form (Pl. 3, figs. 3, 5, 7); however, Squires (1956, p. 19) mentions that both growth forms are present in the species from Idaho. Only one poorly preserved specimen of *"Montlivaltia"* cf. *"M." norica* was obtained from acid residues. Two specimens referrable to *Margarastraea* were also discovered. Small, twiglike branching *Actinastraea ohmanni* (Pl. 1, figs. 3-5) were extracted from acid residues. This is the first report of this European species in North America. It was previously known only from the Norian-Rhaetian Zlambach beds of Austria. Several species of *Astraeomorpha* including *A. confusa* var. *minor* (Pl. 1, fig. 8) are present.

Both *"Thecosmilia" dawsoni* and *"T." suttonensis* are abundant at the Vancouver Island locality. Both were reported by Squires (1956) from Idaho. *"T." suttonensis* (Pl. 3, figs. 2, 4) produces large, compact, branching colonies, and in growth form it differs from other *"Thecosmilia"* colonies in having its branches oriented nearly parallel (Fig. 8A). Species similar to this genus occur at other localities but can be distinguished from *"T." suttonensis* by the more widely diverging branches. Relative to *"T." suttonensis, "T." dawsoni* is a small branching coral (Pl. 3, fig. 3).

No spiriferid brachiopods were recognized but *Terebratula suttonensis* (Pl. 8, fig. 7) is commonly associated with the corals and was probably attached during life. A variety of bivalves dominated by *Minetrigonia suttonensis* is present (Pl. 8, fig. 15). Numerous, very small gastropods 3 to 5 mm long, uncovered from acid residues were sent to Roger L. Batten, of the American Museum of Natural History; however, none could be identified. A trigonid, *Trigonia* (*Kumatrigonia*) sp., similar to that from Idaho was identified from the coral beds. Some poorly preserved foraminifers were noted in thin sections and abundant sponge remains were obtained from acid residue (Table 6). Results of point counts of the fossils in the coral beds are presented in Table 7.

P. M. Kier has made preliminary identifications of several species of small echinoids from the buildups (Table 6). These appear to be entirely new and are very similar to species in the St. Cassiano beds of Italy.

TABLE 7.—*Point Counts of Fossils from Bedding Planes Within the Two Coral Beds at the Vancouver Island Locality.* Figures show percentages from two counts taken in each bed using a grid with dimensions of 25 × 25 units. Each unit area equals 1.25 cm². See Appendix E for location of units.

	Unit 2		Unit 9	
Fossil Group	1	2	1	2
Actinastraea	6.0	.....	15.5	29.8
Elysastraea	34.2	42.9	37.0	51.6
Thamnasteria	40.6	43.6	11.1	.....
"Thecosmilia"	11.0	8.5	19.2	8.5
Brachiopods	5.0	.....	7.2	6.0
Pelecypods	3.2	5.0	10.0	4.1

Discussion.—The coral beds from Lake Cowichan contain abundant corals that constructed thin, patchlike buildups. These appear to have developed in a shallow-water, volcanic region. The occurrence of thin coral buildups at similar stratigraphic positions in various areas of northern and eastern Vancouver Island suggests that corals were widespread in the volcanic marine setting.

The composition of the coral fauna is remarkably similar to that from the Lewiston, Idaho, locality and dissimilar to coral faunas of other areas. The Vancouver Island coral fauna shows closest affinities with the Zlambach beds of Austria. The absence of algae and oolites, although not conclusive evidence, suggests that the coral faunas may have occupied a boreal setting, with water cooler than that further south.

Age.—The age of the coral beds in the Sutton is well established as late Norian. The occurrence of the ammonites *Rhabdoceras suessi, Placites,* and *Choristoceras* in beds associated with the corals places them in the Suessi Zone and the occurrence of the benthonic fauna, according to Tozer (1967, p. 79), suggests upper rather than lower Suessi Zone. Similar age determinations have been made for the coral faunas in the Parsons Bay Formation in other parts of Vancouver Island (Muller, Northcote, & Carlisle, 1974), but coral occurrences in the Quatsino Formation (Jeletzky, 1976) suggest late Karnian to early Norian ages. In the present study, however, none of these other localities were investigated. The Sutton coral fauna is younger than those at most other localities described herein. The similarities of coral and bivalve faunas from Vancouver Island and the Idaho locality suggest that both are of similar age and support the late Norian assignment of the latter.

GRAVINA ISLAND, ALASKA

Setting and stratigraphy.—Smith (1927) reported a coral-reef zone in strata on Gravina Island, near Ketchikan, Alaska. Gravina Island is located at approximately

55° latitude and is one of the many coastal islands that make up the Alexander Archipelago in the panhandle of Alaska. Smith (1927) reported a variety of corals, spongiomorphs, and mollusks from the west coast of Gravina Island. He illustrated these and placed the corals in his interregional lower Norian coral zone. Most of the coelenterates are conspecific with those from the Shasta region of California.

The stratigraphy of Triassic rocks on Gravina Island was presented by Smith (1915), Chapin (1918), and Martin (1926). Fossils present in these rocks indicate a Late Triassic age. Most recently, Berg (1973) mapped and described the rocks on Gravina Island and proposed the name Nehenta Formation for complexly folded and faulted rocks that occur along the west coast. A total thickness of 487 m was estimated for the formation, which consists of basalt, conglomerate, graywacke, sandstone, shale, and limestone. Berg (1973) subdivided the formation into three informal lithologic units: calcareous, conglomeratic, and volcanic members. The calcareous member occurs above the volcanic member and intertongues with the conglomeratic member. The Nehenta Formation unconformably overlies Paleozoic rocks and is overlain by the Chapin Peak Formation, a younger Triassic sedimentary and volcanic unit.

During the summer of 1976, I investigated the Triassic rocks along the west coast of Gravina Island. Due to the dense vegetation and inaccessibility of the coast, float-equipped aircraft were used to reach outcrops along the coast. The various members of the Nehenta Formation were investigated and the corals of Smith (1927) were found to occur in the calcareous member. Two localities contained abundant corals, and these were chosen for study. Due to the structural complications, exact stratigraphic positions of the coral occurrences within the calcareous member could not be determined. The two localities are described below.

Nelson Point Locality

Along the western side of Gravina Island, 1.29 km north of Nelson Cove, SW¼ SE¼ sec. 3, T. 77 S., R. 89 E.

In a sequence of medium- to thin-bedded limestone and shale, a single massive coral bed 2.4 m in thickness was located (Fig. 9A). This coral bed is underlain by 10.6 m of nonfossiliferous, dark-gray limestone. It is overlain with an abrupt contact by fine- to medium-grained, sparsely fossiliferous, dark limestone and shale containing the bivalve *Halobia*.

The coral unit is reefoid and contains in the lower 1.2 m a framework structure of corals and spongiomorphs as well as sponges, brachiopods, gastropods, and bivalves. The mollusks increase toward the top of the unit while the corals decrease in abundance. The upper portion of the unit contains large gastropods of the genus *Purpurina*. The unit as a whole appears to thicken laterally and corals weather out in relief. Pectinid as well as myophorid bivalves are present. Terebratulid and spiriferid brachiopods are common in the reefoid part of the bed. Large branching *Spongiomorpha* 30 cm in diameter as well as *"Thecosmilia"* cf. *"T." fenestrata* and *"T."* cf. *"T." delicatula* are also present. Incrusting *Elysastraea* is abundant at this locality.

Nehenta Bay Locality

Intertidal outcrop at southeast side of Nehenta Bay, SE¼ NW¼ sec. 25, T. 77 S., R. 90 E.

Corals occur in thin beds of limestone and conglomerate in strongly folded strata near an abandoned cabin and copper prospect. Beds dip 25-35° north. Corals and spongiomorphs were illustrated from this locality by Smith (1927), who identified Nehenta Bay as "Three Mile Cove."

Gray, coralliferous limestone at this locality is interbedded with thin, black shale, dark argillite, and conglomeratic sandstone. The sequence containing the corals is approximately 30 m thick and conglomeratic in the lower part. Individual limestone and conglomeratic sandstone beds are thin (10 to 30 cm thick) and alternate with dark, calcareous shale and argillite beds each 5 to 10 cm thick. The shales contain the bivalve *Halobia*. The limestone contains incrusting corals, crinozoan columnals, echinoid plates, and molluskan debris. Generally the corals are poorly preserved. *Elysastraea profunda* is common as well as *Palaeastraea descussata*. Massive colonies of *Stromatomorpha* are also present.

The lower part of the sequence contains poorly sorted conglomeratic sandstone, limestone, and shale beds. Large angular clasts 1 to 10 cm in diameter occur in the conglomeratic beds. These clasts consist mainly of limestone, but some volcanic rock fragments also occur. Corals in the conglomeratic beds occur as rock clasts and apparently also incrusting the rock fragments. *Elysastraea* is common. Bivalves are present including *?Myophoria* but all are poorly preserved and fragmental. Nowhere do corals form a true framework structure such as that found at the Nelson Point locality.

Lithofacies.—Several lithofacies occur in the calcareous member of the Nehenta Formation. Corals appear in greatest abundances in the limestone intervals that also occur, as mentioned above, in conglomeratic beds interbedded with the limestone. Limestones at the Nelson Point locality contain bioclastic grainstone and packstone facies. The corals and spongiomorphs occur in a coral-mollusk bindstone-framestone facies that characterizes the lower part of the coral interval, whereas the upper part contains bioclastic packstone-grainstone facies. The latter is moderately sorted and contains abraded echinozoan and crinozoan grains with abundant pellets and rounded to subrounded limestone clasts. Large, whole bivalves and gastropods are also abundant along with small amounts of volcaniclastic debris.

Thin sections from most of the limestone beds at the Nehenta Bay locality reveal much coarser facies types. Poorly sorted, bioclastic grainstones and packstones containing abundant angular intraclasts of numerous lithologies including much volcaniclastic material are present. The upper part of the section yielded more pure carbonate rocks, whereas the lower part of the section contained considerably more volcaniclastic material along with limestone clasts and coarse skeletal material. Angular clasts ranging from 0.5 to 15 mm in diameter are abundant and coral debris is occasionally present in this part of the section.

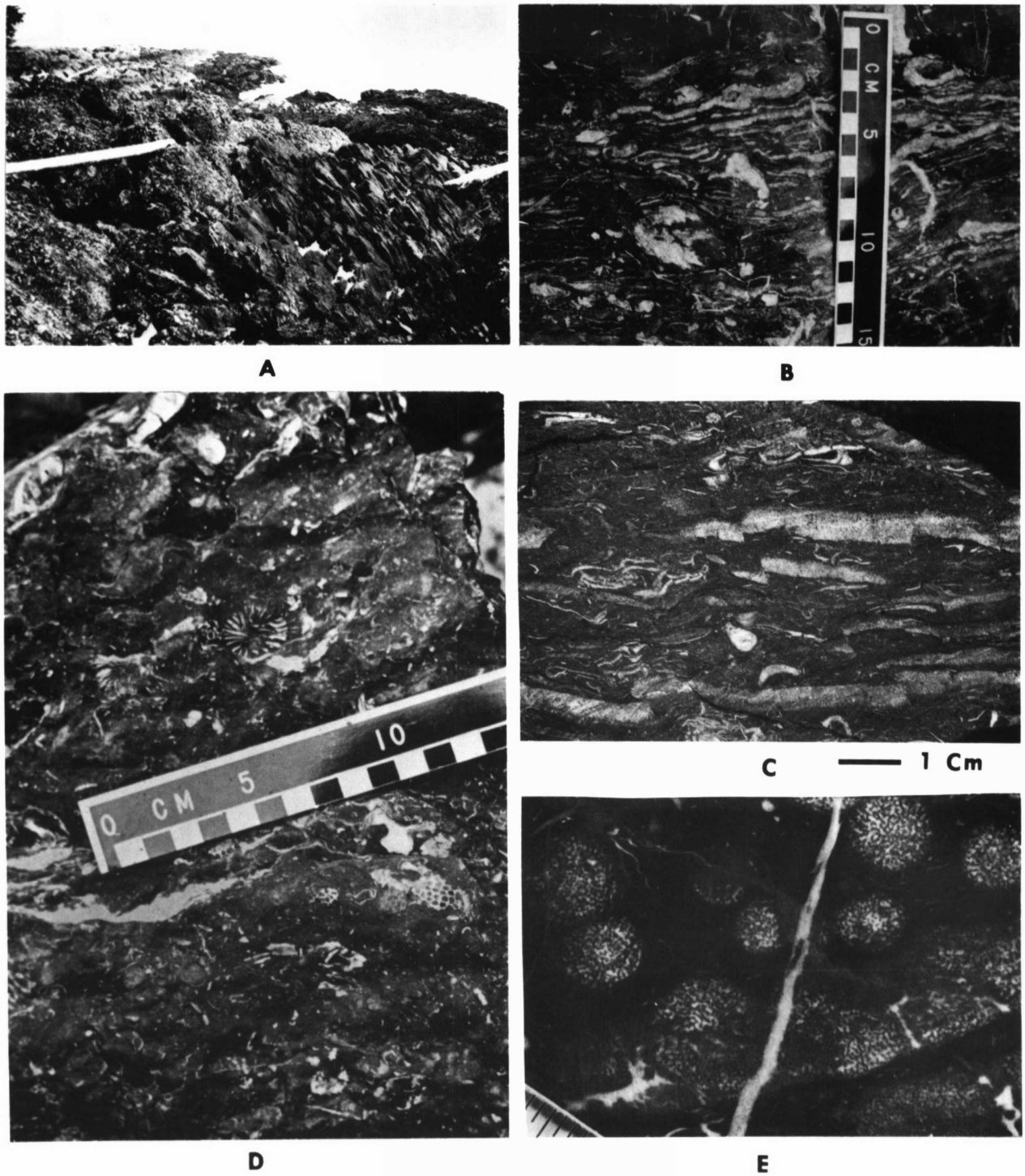

FIG. 9. Coral buildups in Alaska.———A. Outcrop on the coast of Gravina Island, Alaska, showing steeply dipping beds. Log at left rests on coral bed.———B. Thin, ribbonlike incrusting spongiomorphs on vertical exposure of dark limestone at Iliamna Lake, Alaska.———C. Sawed slab (KUMIP 113682) from outcrop in B, cut normal to bedding and showing incrusting spongiomorphs and abundant molluskan debris.———D. Bedding plane showing abundant corals and other broken debris in the fine-grained, dark limestone at Iliamna Lake, Alaska. Small solitary *"Montlivaltia" norica* in center above scale. Incrusting *Elysastraea* to the right just below scale.———E. Polished surface cut normal to bedding, showing details of *Spongiomorpha ramosa,* one of the dominant spongiomorphs at the Iliamna Lake locality (KUMIP 113652). Scale in millimeters.

In most thin sections, echinoderm and mollusk grains are much more abundant than fragments of corals or spongiomorphs. Algae or algal grains do not appear to be present in any of the intervals studied. Also, no foraminifers were observed.

Fossils.—A list of fossils of the coral beds on Gravina Island is presented in Table 8. Sponges, spongiomorphs, corals, brachiopods, and mollusks were collected and identified. Only a few small, poorly preserved calcisponges were found, and these could not be identified.

TABLE 8.—*Fossils from Gravina Island, Alaska.*

PORIFERA
indet. calcisponges
COELENTERATA
Hydrozoa
Spongiomorpha gibbosa Frech
S. ramosa Frech
Stromatomorpha californica Smith
Scleractinia
Actinastraea cf. *A. juvavica* (Frech)
Elysastraea parva (Smith)
E. profunda (Reuss)
Margarastraea eucystis (Frech)
"Montlivaltia" norica Frech
Palaeastraea borealis (Smith)
P. descussata (Reuss)
Thamnasteria cf. *T. borealis* Smith
"Thecosmilia" cf. *"T." delicatula* (Frech)
"T." fenestrata Reuss
"T." norica Frech
BRACHIOPODA
Zugmayerella cf. *Z. osmana* (Bittner)
indet. spiriferids
indet. terebratulids
MOLLUSCA
Bivalvia
Lima cf. *L. blackburnei* Smith
Myophoria sp.
indet. carditaceans
indet. pectinids
Gastropoda
Protocula bassetti Smith
Purpurina gravinaensis Smith
Zygopleura sp.
indet. neritaceans

Spongiomorphs are abundant, especially the branching *Spongiomorpha ramosa* and massive *Stromatomorpha californica* (Pl. 6, fig. 5). The latter was described by Smith from the Shasta area of California. It is a massive coelenterate with a coenosteum over 30 cm in thickness. The most abundant corals are *Palaeastraea descussata, P. borealis,* and *Elysastraea profunda.* Both species of *Palaeastraea* have mushroom-shaped or branching coralla (Pl. 4, fig. 5) while *E. profunda* is strictly incrusting. *"Thecosmilia"* is well represented but usually poorly preserved. Only one genus of *Actinastraea* was collected—*A. juvavica,* which is not a common species. Most of the remaining species are rare. Coelenterates reported by Smith (1927) but not identified from collections in this study are *Margarastraea alaskana, Thamnasteria rectilamellosa* var. *minor sensu* Smith (= *T. smithi*), *Halomitra triadica,* and *Margarastraea grandissima.*

Both terebratulids and spiriferids are present but only *Zugmayerella* cf. *Z. osmana* was identified. This brachiopod is widely distributed in upper Karnian to lower Norian rocks in North America (P. R. Hoover, pers. commun., April, 1977).

Mollusks, especially gastropods, are abundant. The gastropod *Purpurina gravinaensis* (Pl. 9, fig. 7) is exceedingly abundant in close association with the corals. *Prolocula bassetti* (Pl. 9, fig. 8) is another common gastropod. Bivalves are common but most are poorly preserved and unidentifiable.

Discussion.—The corals and spongiomorphs at Gravina Island do not occur in appreciable thicknesses of limestone. They occur instead in thin beds and lenses of limestone, intercalated with shale and volcaniclastic rocks. Corals and spongiomorphs, however, construct thin limestone buildups similar in thickness to those at Vancouver Island. Textural features of the carbonate rocks in thin section indicate that the corals and associated biota existed in a shallow-water, frequently high-energy environment, situated close to a source area from which volcaniclastic material was being derived. Although corals and spongiomorphs are present in volcaniclastic limestone, their greatest development occurs in purer carbonate rocks in the absence of volcaniclastic material. Some corals, rather than building reefoid structures, are scattered in thin conglomerate and breccia beds, where they appeared to have incrusted upon rock debris. In general, this setting was not conducive to coral growth.

Coral growth forms at Gravina Island tend toward small sizes, dominantly thin and incrusting or branching. Few of the species reach dimensions comparable to those observed in other areas of the study. The coral and spongiomorph fauna is very similar to that from Nevada, California, and Oregon. Many of the 13 coelenterate species identified from Gravina (Table 8) occur at other localities.

Age.—Early workers who mapped and described the Triassic rocks of Gravina Island assigned them to the Upper Triassic on the basis of the presence of the bivalve *Halobia superba* in the shale intervals (Smith, 1915; Chapin, 1918; Martin, 1926). These early workers recognized that most of the benthonic fauna was generally provincial and of little biostratigraphic value. According to Tozer (1967), *Halobia superba* is distinctive and in North America characterizes the upper Karnian

to lower Norian (Welleri-Kerri) zones.

Berg (1973) placed the *Halobia* beds in the calcareous member of the Nehenta Formation. He concluded that the rocks of the calcareous member range from early to late Norian in age. This conclusion was based on the occurrence of *Halobia* in the lower part of the member, and of *Heterastridium* in the upper part. *Heterastridium* is a cosmopolitan hydrozoan of questionable affinities which had a pelagic or planktonic mode of life (Gerth, 1915; Flügel, 1960). Silberling and Tozer (1968, p. 31) and Campbell (1974) reported this genus to be restricted to the Norian, ranging into the Upper Norian Suessi Zone.

During field work, the corals were observed in association with the *Halobia* beds. *Heterastridium* is absent from strata containing the corals. On the basis of these findings, I place the coral occurrences on Gravina in the lower Norian Kerri Zone. The corals of Gravina Island are thus roughly contemporaneous with many of the other coral occurrences. The early Norian age assignment is compatible with the occurrence of the brachiopod *Zugmayerella* cf. *Z. osmana.*

ILIAMNA LAKE, ALASKA

Setting and stratigraphy.—The first mention of a lower Norian coral reef zone at Iliamna Lake was made by Smith (1912), who discussed a coral horizon near Cook Inlet. The coral species listed by Smith were identical to those known from California and Oregon, and their discovery at 60 degrees latitude made them the northernmost Triassic coral fauna known.

Corals from this locality occur in dark limestone on the north shore of the lake. Martin and Katz (1912) discussed the geology of the region and concluded that these abundant corals probably represented a reef. The coral-bearing limestone is massive and fine grained and contains much bituminous matter. Martin and Katz assigned the limestone to the Upper Triassic, mainly on the basis of the corals, but also noted the occurrence of Upper Triassic bivalves and brachiopods.

Unfortunately, the stratigraphic relationships at the Lake Iliamna locality are obscure. The rocks in contact with and intruding the limestone are basic igneous rocks that have not been dated but are believed to be Jurassic. Other rocks in contact with the limestone are Tertiary tuffs and volcanics. Limestone beds of assumed Triassic age occur in the immediate vicinity in contact with volcanic rocks but contain no fossils. Limestone at the Lake Iliamna locality may be correlated with the Upper Triassic Chitistone or Nizina Limestone of the Copper River Basin and Chitina Valley (Martin and Katz, 1912; Martin, 1926). These rocks are known to range from Karnian through Norian ages. Due to igneous intrusions and stratigraphic and structural complications, the coral-bearing limestone at Lake Iliamna is isolated, and no formal stratigraphic name has yet been proposed for it. While this manuscript was in preparation, I learned that Robert Detterman and Bruce Reed of the U. S. Geological Survey are engaged in a geologic study of the Iliamna Quadrangle. According to Detterman (pers. commun., July, 1977), they place the coral locality in the upper part of the Kamishak Chert, a local Upper Triassic unit consisting of 610 m or more of dark-banded radiolarian chert with intrusive volcanics and interbedded dark shale, sandstone, and limestone (Martin and Katz, 1912). The only fossils at the type locality at Kamishak Bay are *Monotis subcircularis,* a deepwater or pseudoplanktonic bivalve.

During the summer of 1976 I investigated the coral-bearing limestone along the north shore of Lake Iliamna. To the east and west along the shore of the lake, the limestone is in contact with and intruded by basic volcanic rocks, and to the south it appears to have an unconformable contact with Tertiary tuffaceous and volcanic breccias. Due to a dense cover of tundra vegetation, the limestone does not crop out extensively away from the lake shore. Corals and spongiomorphs are abundant in certain horizons in the dark limestone, but few biotic framework structures are present. Structural complexities and igneous intrusions make estimates of thickness of the limestone difficult. At least 50 m of dark-gray to black, fine-grained limestone may be present. A description of part of these rocks is given in Appendix F.

Lithofacies.—Thin sections of limestone from the Lake Iliamna locality reveal sparsely fossiliferous, partly recrystallized wackestone, skeletal wackestone, packstone, and bindstone facies. All samples analyzed revealed fine-grained (micritic) matrices with large amounts of very fine carbonaceous material, which gives the limestone its dark color (Fig. 9E). The grains are composed mostly of spongiomorphs with some coral skeletons. Corals frequently incrust large spongiomorph grains.

The spongiomorph bindstone facies occurs throughout the section. It is characterized by successive, closely spaced incrustations (0.5 to 2.0 cm thick) of *Spongiomorpha ramosa,* which effectively trap fine-grained carbonate (micrite) and molluskan shell debris (Fig. 9B, C; Pl. 6, fig. 4). Occasional large borings occur in the sporgiomorph skeletons, but there is no evidence of extensive bioerosion.

The packstone facies consists of spongiomorph, molluskan, and coral grains in a micrite matrix. Skeletal grains are poorly sorted and many are broken. Large, thin bivalve shells and spicular (?sponge) material are usually present. Fragments of *Solenopora* and *Gymnocodium* are occasionally present but not significant in

abundance. Both whole and broken corals are present. Less common constituents include rare foraminifers and crinoid and echinoid plates and spines. Completely intact, spherical or ellipsoidal *Heterastridium* (1 to 3 cm diameter) are common (Pl. 6, fig. 8, 9).

The wackestone facies alternates with the packstone and bindstone facies. It consists of occasional small, thin-shelled bivalves and abundant spicular (?sponge) material. Whole specimens of *Heterastridium* are present in this facies as well as the packstone facies. Corals are not as common in the wackestone facies (Pl. 10, fig. 5).

Some of the limestone, particularly that in contact with volcanic intrusions, is highly altered and recrystallized, by both volcanism and metamorphism and it contains abundant stringers and veins of calcite. This type of lithology is prevalent at the top of the measured section, and little information concerning original textures and composition can be derived from these limestones.

Fossils.—A variety of spongiomorphs and corals is present (Table 9). Percentage data for the abundance of the major groups in the bindstone and packstone facies is given in Table 10. Spongiomorphs clearly dominate the fauna in both facies. A few foraminifers were identified from thin sections, and rare unidentified chambered calcisponges 1 to 2 cm long were observed at the outcrop.

Five species of Hydrozoa are present (Table 9). *Heterastridium conglobatum* is quite common throughout the sequence. This hydrozoan is a strictly Norian form in North America and has been reported from McKinley National Park by Smith (1927). It may be present at Gravina Island (Berg, 1973), and Silberling and Tozer (1968) reported occurrences in Nevada, Canada, and Alaska. *H. conglobatum* is also known from New Zealand, southern Europe, and Asia (Campbell, 1974). In many of these occurrences *Heterastridium* occurs in strata containing a pelagic or planktonic fauna of nautiloids, ammonites, and halobiid bivalves. Lake Iliamna is the only locality where this hydrozoan was found to occur in association with corals.

Spongiomorpha ramosa is a branching, incrusting, or knoblike spongiomorph which is abundant at Lake Iliamna (Pl. 4, fig. 11). This species occurs frequently *in situ* with parallel branches 5 to 15 cm long (Fig. 9E). The abundant form *S. gibbosa* occurs as cylindrical stacks or as botryoidal masses up to 10 cm thick. *S. acyclica* (Pl. 6, fig. 7) is less common, with smaller mushroom-shaped colonies 5 cm thick. A few specimens (Pl. 5, fig. 7) resemble *Spongiomorpha* sp. A Flügel and Sy (1959, Pl. 3, fig. 3). Many spongiomorphs are incrusted by corals. Spongiomorphs range in abundance from 40 to 73% (Table 10) and dominate the biota.

TABLE 9.—*Fossils from the Lake Iliamna Locality, Alaska.*

FORAMINIFERA
Nodosaria sp.
endothyrids

PORIFERA
indet. calcisponges

COELENTERATA
Hydrozoa
Heterastridium conglobatum Reuss
Spongiomorpha acyclica Frech
S. gibbosa Frech
S. ramosa Frech
S. cf. *S.* sp. A Flügel and Sy
Scleractinia
Actinastraea sp.
Coccophyllum cf. *C. acanthophorum* Frech
Elysastraea major (Frech)
E. profunda (Reuss)
E. cf. *E. vancouverensis* (Clapp and Shimer)
Margarastraea cf. *M. grandissima* (Frech)
"Montlivaltia" norica Frech
Oppelismilia cf. *O. zitteli* (Frech)
Thamnasteria cf. *T. smithi* Squires
"Thecosmilia" cf. *"T." dawsoni* (Clapp and Shimer)
"T." cf. *"T." suttonensis* (Clapp and Shimer)

BRACHIOPODA
indet. spiriferaceans

MOLLUSCA
indet. bivalves including halobiid forms
indet. coiled nautiloid cephalopod
indet. small high-spired gastropods

ECHINODERMATA
indet. crinoid columnals
indet. echinoid spines and plates

ALGAE
Gymnocodium cf. *G. bellerophontis* (Rothpletz)
Solenopora sp.

Ten species of corals are present (Table 9). Most abundant are *"Montlivaltia" norica, Actinastraea* sp., and *Coccophyllum* cf. *C. acanthophorum*. The latter occurs as both incrusting and branching growth forms. This species frequently incrusts spongiomorphs (Pl. 4, fig. 7).

TABLE 10.—*Percentages of the Major Biota, Lake Iliamna Locality, Alaska, Derived from Three Grid Counts in Each Lithofacies.* Grid size 25 × 25 units, each 2.5 cm².

	Boundstone Lithofacies			Packstone Lithofacies		
Fossil Group	1	2	3	1	2	3
Corals	41.4	11.9	13.8	30.1	18.5	16.0
Spongiomorphs	40.9	73.2	68.8	40.5	49.5	50.1
Heterastridium	.....	4.5	1.0	9.8	.....	0.6
Brachiopods	3.1	.....	6.4	8.6	4.3	3.0
Gastropods	3.0	3.0	4.0	.....	.....	1.6
Bivalves	9.0	5.4	6.0	10.0	20.1	22.7
Echinoderms	2.6	.....	.....	1.0	5.0	6.0
Algae	.....	2.0	.....	.....	2.7	.....

Four incrusting species of *Elysastraea* are present. *E. profunda* is the most common and assumes an incrusting growth form (Pl. 10, fig. 4). Much rarer is *E. major,* distinguished by unusually large corallites. While the spongiomorphs are abundant and build unusually large branching and massive skeletons, the corals are less abundant and are generally characterized by small, thin colonies. Cuplike, solitary *"Montlivaltia" norica* appears to be one of the most abundant corals. *"Thecosmilia"* cf. *"T" suttonensis* is present but is neither abundant nor does it form the framework structures so typical of other localities. Another distinguishing feature of the Iliamna locality coral associations is the frequent incrustations of spongiomorphs by corals such as *Coccophyllum*. This is the reverse of relationships observed at most other localities. These relationships suggest that at Lake Iliamna the spongiomorphs were assuming biologic roles usually held by the corals. This recalls the Black Marble Quarry locality in Oregon, where spongiomorphs are also abundant.

Palaestraea descussata was illustrated from Lake Iliamna by Smith (1927, Pl. 121), but after examining Smith's specimens, I found them too recrystallized for positive identification. Other fossil elements include spiriferid brachiopods and abundant unidentified bivalves, mostly small, thin-shelled forms (Pl. 10, fig. 6). Small gastropods are present but are not common. A single unidentified, small coiled nautiloid was observed in one thin section, but no other cephalopods were observed or collected. Occasional echinoid and crinoid plates are present, but none could be identified.

Two forms of calcareous algae, *Solenopora* and *Gymnocodium,* are present but not very common. The former occurs as small nodular masses a few centimers in diameter, while the latter is branching (Pl. 10, figs. 6, 7). Both are red algae, and occur both as whole and broken thalla. The other red algae resembles *G. bellerophontis,* illustrated by Johnson (1961, Pl. 20). According to Johnson, this genus was known only from the Permian. The present finding appears to extend its range into the Triassic. Both species of algae are rare at Lake Iliamna.

Discussion.—The spongiomorph-coral limestone at Lake Iliamna is significant because it is one of the northernmost Triassic coral localities known. True reefoid or framework structures are absent, although incrusting spongiomorphs do form thin bindstone textures at certain intervals. The fauna contains corals and spongiomorphs known from localities as far south as California. The coral and spongiomorph fauna closely resembles that of Vancouver Island and Idaho. *Heterastridium,* common at the Iliamna locality (Pl. 6, figs. 8, 9) is absent from any of the other coral localities of North America. *Heterastridium* appears to have been a pelagic hydrozoan and in life may not have been part of the benthonic biota. Pseudoplanktonic halobiid bivalves are also present.

Since true framework structure is absent, the limestone does not appear to be a reef but, judging from the diversity and abundance of the benthonic biota, was probably an organic bank. The presence of bituminous material in the dark limestone could be indicative of original euxinic conditions in the sediment.

Various aspects of the carbonates and the sparsity of the algae suggest that the deposit accumulated in water much deeper than the normal reef environment and perhaps near the maximum depth of the algae. All the carbonates are fine grained and there are no grainstone facies, oolites, or algal-coated grains such as described from other coral localities. This indicates deposition in quiet water well below wave base. The complete and generally unabraded condition of most fossils and the presence of halobiid bivalves and *Heterastridium* are compatible with the assumption of deposition in deeper water.

The occurrence of algae appears at first to contradict a deepwater hypothesis. However both species are red algae (Rhodophyta), and among the various algal groups, these have the greatest tolerance for cold and deep water (Johnson, 1961; Ginsburg, Rezak, & Wray, 1972; Heckel, 1974). Today, red algae occur widely in temperate and polar regions of the ocean. Off the coast of Norway red algae are known at depths of 200 m (Johnson, 1961). None of the warm, shallow-water forms, such as dasycladaceans or codiaceans, are present.

Age.—The age of the dark limestone at Iliamna has never been well established. Martin and Katz (1912) suggested that the corals were part of Smith's (1912) early Norian interregional coral zone, but subsequent work has shown that these coral zones actually differ widely in age.

According to N. J. Silberling (pers. commun., March, 1977), *Monotis subcircularis* has been discovered in noncoralline rocks at Contact Point in Cook Inlet, 48 km southeast of the Iliamna Lake locality. *M. subcircularis* is diagnostic of the upper Norian and may be the same as poorly preserved halobiid forms observed in this study and also reported by Martin and Katz (1912, p. 45).

The most age-diagnostic fossil in the coral sequence is *Heterastridium,* which is characteristic of the Late Norian Suessi Zone, according to N. J. Silberling (pers. commun., March, 1977). I therefore place the coral-bearing rocks of Iliamna Lake in the Suessi Zone. This assignment is supported by the similarity of many of the coral species with those from the Vancouver Island and Idaho localities, both of which have been assigned to the Suessi Zone.

REEVALUATION OF TRIASSIC BUILDUPS IN NORTH AMERICA

Reevaluation of the Triassic coral buildups of North America has resulted in a much better understanding of the actual nature of these structures. It has produced some significant findings as well as some major problems. These problems include 1) age and stratigraphic distribution of the buildups, 2) paleoecology of the corals and depositional environment in terms of water depth, 3) paleobiogeography and distribution of the coelenterates. The following chapters address these problems in terms of field and research findings, comparing the Triassic buildups of North America with both modern reef structures and Triassic examples in the Alps.

AGE AND STRATIGRAPHIC DISTRIBUTION

During the Triassic, scleractinian corals and hydrozoans were widespread from California to Alaska, but Smith's (1912, 1927) idea that all of the coral occurrences constitute one great interregional reef zone of early Norian age is disproven, because they are now known to range from late Ladinian to late Norian. Figure 10 shows the time-stratigraphic distributions, correlations, and ages of the coral buildups at each locality in North America. The recognition of European Triassic stages in North America was discussed by Silberling and Tozer (1968). The North American biostratigraphic zones used in Figure 10 were defined by Tozer (1967) and Silberling and Tozer (1968). Most are based on the ranges of certain ammonoids and halobiid bivalves. The criteria used in placing each of the coral occurrences at a particular level are given at the end of the locality description. The placement and correlation of the formational units in Figure 10 is based on assessment of diagnostic fossil taxa, a review of the relevant literature for each area under discussion, and consultation with U.S. Geological Survey workers, especially N. J. Silberling.

It must be emphasized, however, that some correlations of formational units are uncertain. Similarly, precise positioning of some of the coral horizons within a particular formation may also be approximate. Figure 10 is oriented to time-stratigraphy, and vertical dimensions do not reflect actual thicknesses of units. As discussed

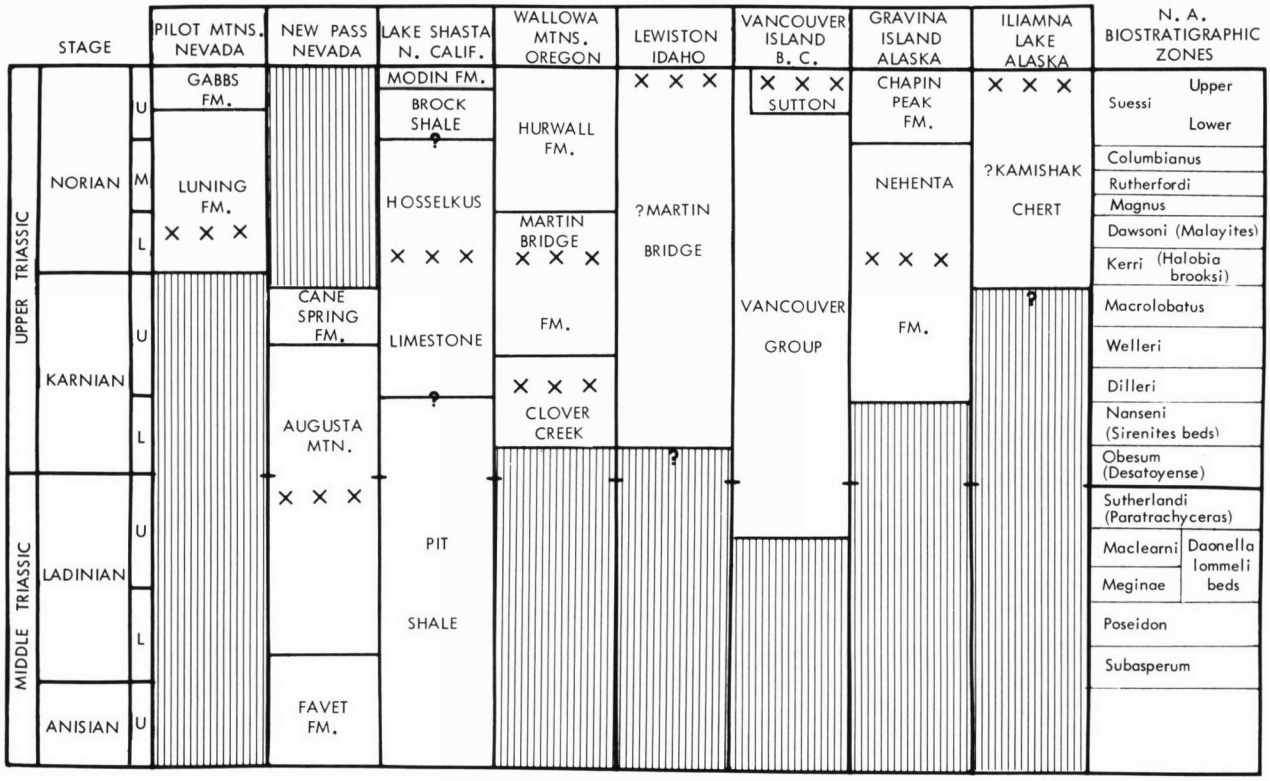

FIG. 10. Time-stratigraphic correlation chart for Middle and Upper Triassic rocks of North America. Occurrences of coral buildups are indicated by X. Vertical lines show gaps in the rock record.

in the descriptive chapters, some of the boundaries of rock units are uncertain, and these are indicated by question marks.

The oldest coral occurrences, those at New Pass, are Middle Triassic (late Ladinian) (Fig. 10). No other Middle Triassic coral occurrences are present in the study area. Four of the other localities, the one at Mina, Nevada, and those in California, Oregon, and Alaska, are early Norian in age. The locality at Mina, although early Norian, may be slightly younger than the others; Silberling (pers. commun., March, 1977) placed it high in the lower Norian between the Kerri and Magnus zones. Thus only four localities out of the eight investigated fall into the area of Smith's early Norian "coral reef" zone.

The limestone in the Black Marble Quarry in the northern Wallowa Mountains of Oregon is late Karnian (Dilleri Zone) and represents an older occurrence. According to Tozer (1967), other coral horizons of similar age occur in the western Cordillera of Canada. These occurrences, however, are not included in this study. The remaining three localities are late Norian in age. The age of the coral occurrences at Vancouver Island and Iliamna Lake is fairly well established and fossil evidence from the Lewiston locality indicates that it is of late Norian age.

From Figure 10 and the locality descriptions it can be seen that coral development in the form of thin, reefoid buildups was most frequent in both the early Norian and late Norian. Generally, coral buildups of early Norian age characterize the southern part of western North America, whereas late Norian buildups characterize the north (Fig. 10). In addition, late Karnian occurrences are known in Oregon, and others have been reported from British Columbia and the Yukon Territory (Tozer, 1970).

Muller (1936a) denied Smith's concept of a single lower Norian coral reef zone, and showed that many coral faunas of differing ages contain the same species. He concluded that Triassic corals were of no value in biostratigraphy. The list of North American Triassic coelenterates (Table 11), however, shows that whereas some species are almost ubiquitous, others, especially corals, are restricted to certain localities. The similarities are brought out in a more graphic manner by comparing the species composition of various localities using the index of similarity (Odom, 1971) (Table 12). This index is defined as: $S = 2C/(A + B)$, where $A =$ number of species in one sample, $B =$ number of species in a second sample, and $C =$ number of species the two samples have in common. It has a range of 0 to 1, with 1 indicating identical faunas and 0 representing no similarity at all.

The index of similarity is quite revealing when applied to the species distribution data in Table 11. Comparisons between Oregon and Gravina and between Gravina and Shasta show the highest similarity values (0.83 and 0.80), as shown in Table 12. Table 12 shows that based on coelenterate similarity values, localities at Mina, Nevada; Shasta, California; Wallowas, Oregon; and Gravina Island are all similar (0.54 to 0.83) but different from other localities. Lewiston, Idaho, Vancouver Island, and Iliamna Lake are also grouped on the basis of their similarity (0.55 to 0.83) but appear distinct from other localities. This suggests that it is possible to distinguish early Norian from late Norian coelenterate faunas. Also, as would be expected, the Ladinian locality at New Pass shows the least similarity with the Norian localities. Simple cluster analysis of the similarity data clearly shows the distinction of the early and late Norian and Ladinian coelenterate faunas (Fig. 11), demonstrating that the coelenterates, especially the corals, have some biostratigraphic value. Late and early Norian assemblages are clearly distinguishable. Characteristic species of the late Norian are *Coccophyllum acanthophorum*, *"Thecosmilia" suttonensis*, *"T." dawsoni*, *Elysastraea vancouverensis*, and *Elysastraea major*, and of the early Norian: *Actinastraea juvavica*, *A. shastensis*, *"Thecosmilia" fenestrata*, *"T." delicatula*, *Elysastraea parva*, and *Spongiomorpha dendriformis*. These species appear to be unique to the early and late Norian in North America.

Karnian and Ladinian coelenterate faunas are not well represented in this study. The Black Marble Quarry, Oregon, and New Pass, Nevada, are the only localities where corals representing these intervals of time have been studied. Nevertheless, from available data, the coelenterate faunas from these two localities appear to be distinctly different from each other and from those of Norian age. Examinations of abundant Karnian coral faunas of Canada (Tozer, 1967, 1970) may add more information and allow more meaningful comparisons. From this study, the Ladinian is characterized by several unidentified astrocoeniids and *Cassianastraea* cf. *C. reussi* known from similar age sequences of Italy. The Karnian contains the coral *Margarosmilia* cf. *M. confluens*, which may be distinctive (Table 11). Such common species as *Elysastraea profunda* and *"Montlivaltia" norica* are long ranging and are not considered to be biostratigraphically useful.

The present study suggests that the Triassic corals have as yet unrealized potential in biostratigraphy. Although they are not so short ranging as ammonite species, they may nevertheless be of some biostratigraphic value because of their frequent occurrence in strata devoid of ammonites or other diagnostic fossils.

PALEOECOLOGY

Depositional environments.—During this study, oc-

TABLE 11.—*Distribution of North American Triassic Coelenterate Species.* Symbols: ×, from this study; *, Black Marble Quarry, Ore.; Sm, in Smith (1927); Sq, in Squires (1956); A, Limestone Alps: Germany, Austria, and Italy (Frech, 1890; Laube, 1865; Flügel and Sy, 1959); U, USSR (Melnikova, 1967, 1972); J, Japan (Kanmera, 1964); S, Slavic countries (Kolosvary, 1966, 1967; Roniewicz, 1974); T, Timor (Vinassa de Regny, 1915); C, China (Wu, 1975).

Species	Mina	New Pass	Calif.	Ore.	Idaho	Vancouver	Gravina	Iliamna	Outside North America
SCLERACTINIA									
Actinastraea idahoensis	....	....	....	....	×	×	....	....	....
A. juvavica	×	?	×	×	....	....	×	....	A
A. martini	×	....	....	....	....	....	Sm	....	....
A. ohmanni	....	....	....	....	....	×	....	....	A
A. schafhaeutli	....	....	....	....	×	×	....	....	A,U
A. shastensis	×	....	×	....	....	....	?Sm	....	....
A. waltheri	×	....	....	....	....	....	....	....	A
A. sp. 1	....	×	....	....	....	....	....	....	....
A. sp. 2	....	×	....	....	....	....	....	....	....
Astraeomorpha confusa	×	....	....	....	....	....	....	....	A,U,S,T
A. confusa var. *minor*	×	....	....	....	....	×	....	....	A,U
A. cuneata	....	....	....	....	×	×	....	....	....
Cassianastraea reussi	....	×	....	....	....	....	....	....	A
Coccophyllum acanthophorum	....	....	....	....	×	×	....	×	A
Elysastraea austriaea	×	....	....	....	....	....	....	....	A
E. major	....	....	....	....	Sq	×	....	×	A,S
E. norica	×	....	....	....	....	....	....	....	A
E. parva	×	....	×	....	....	....	×	....	....
E. profunda	×	....	Sm	×	×	×	×	×	A,S,J
E. vancouverensis	....	....	....	....	×	×	....	×	....
E. sp. A	....	×	....	....	....	....	....	....	....
Margarastraea eucystis	×	....	Sm	....	....	....	×	....	A
M. grandissima	....	....	Sm	....	....	....	Sm	×	A
M. norica	×	....	....	....	....	....	....	....	A
Margarosmilia confluens	....	....	....	*	....	....	Sm	....	A,S
"Montlivaltia" marmorea	×	....	....	....	....	....	....	....	A,S,T
"M." ?martini	....	....	....	....	....	....	....	Sm	
"M." norica	×	....	×	×	×	×	×	×	A,J,S,T
Opelismilia zitteli	....	....	....	....	×	....	....	×	A,J,U
Palaeastraea borealis	....	....	....	....	....	....	×	....	....
P. descussata	×	....	Sm	....	....	....	×	....	A,S
Pinacophyllum parallelum	×	....	....	....	....	....	....	....	A
P. parviseptum	....	....	....	....	Sq	....	....	....	....
Stylina norica	....	....	....	....	Sq	....	....	....	A
Stylophyllum paradoxum	....	....	....	....	×	....	....	....	A
Thamnasteria borealis	×	....	....	*	....	....	×	....	....
T. norica	×	....	....	....	....	....	....	....	A
T. rectilamellosa	×	....	×	....	....	....	....	....	A,U,J,S
T. smithi	×	....	×	....	×	×	Sm	×	....
"Thecosmilia" dawsoni	....	....	....	....	×	×	....	×	?A,S
"T." delicatula	×	....	×	×	....	....	×	....	?A
"T." fenestrata	×	....	×	×	....	....	×	....	A,T
"T." norica	×	....	....	Sm	....	....	....	....	A,T
"T." suttonensis	....	....	....	....	×	×	....	×	?A,S,T,?C
HYDROZOA									
Heptastylis aquilae	....	....	Sm	×	....	....	....	....	....
H. oregonensis	....	....	....	×	....	....	....	....	....
H. stromatoporoides	×	....	....	....	....	....	....	....	A
Heterastridium conglobatum	....	....	....	....	....	....	....	×	A
Spongiomorpha acyclica	....	....	....	....	....	....	....	×	A
S. californica	....	....	Sm	....	....	....	×	....	....
S. dendriformis	×	....	Sm	×	....	....	Sm	....	....
S. gibbosa	×	....	....	....	....	....	×	×	A,S,T
S. minor	×	....	....	....	....	....	....	....	A,S
S. ramosa	....	....	Sm	....	....	....	×	×	A,S
S. tenuis	×	....	....	×	....	....	....	....	....
S. sp. A. Flügel	....	....	....	....	....	....	....	×	A
?Tubulitrypa maculata	....	....	....	....	×	....	....	....	A
?Zlambachella alpina	....	....	....	....	×	....	....	....	A

TABLE 12.—*Comparison of Coelenterate Faunas in the Triassic of Western North America.* Numbers are derived from the Index of Similarity (Odum, 1971) and based on the species listed in Table 11.

	Mina	New Pass	Shasta	Wallowa Mts.	Lewiston	Vancouver Island	Gravina Island	Iliamna Lake
Mina	1.00	0.12	0.58	0.59	0.14	0.20	0.61	0.18
New Pass	.....	1.00	0.09	0.12	0.00	0.00	0.08	0.00
Shasta	.....	.....	1.00	0.54	0.18	0.21	0.80	0.31
Wallowa Mts.	.....	.....	.....	1.00	0.14	0.17	0.83	0.15
Lewiston	.....	.....	.....	.....	1.00	0.79	0.17	0.56
Vancouver Island	.....	.....	.....	.....	.....	1.00	0.19	0.55
Gravina Island	.....	.....	.....	.....	.....	.....	1.00	0.34
Iliamna Lake	.....	.....	.....	.....	.....	.....	.....	1.00

currences of Triassic corals that have been consistently referred to in the literature as "coral reefs" have been found to be only thin, laterally restricted buildups or coral-colonized banks (*i.e.,* flat-topped elevations on the sea floor). Almost all are not true coral reef structures. Few of the coral buildups show the types of biologic zonation typical of modern shallow-water reefs and most of the Triassic coelenterate colonies are much smaller than those of modern reef-building species. Field investigations and petrographic analysis reveal that most of the coral buildups developed in relatively quiet-water settings, some of which may have been deeper than is usual for reef systems.

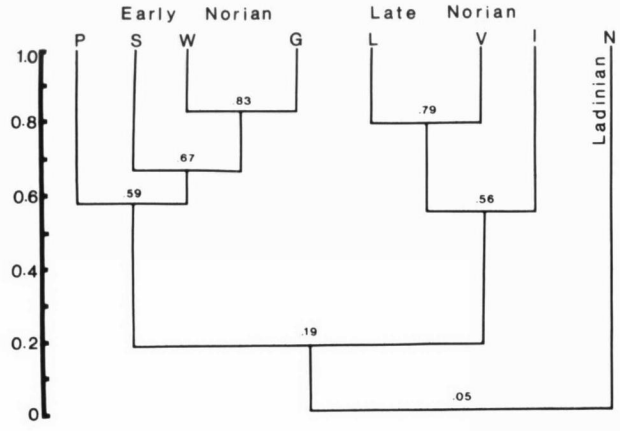

FIG. 11. Dendrogram cluster analysis of the coelenterate similarity data in Table 14 constructed on the basis of weighted pair groups with arithmetic averages. Letters refer to localities as follows: *P,* Pilot Mountains, Nevada; *S,* Lake Shasta, California; *W,* Wallowa Mountains, Oregon; *G,* Gravina Island, Alaska; *L,* Lewiston, Idaho; *V,* Vancouver Island, B. C.; *I,* Iliamna Lake, Alaska; *N,* New Pass, Nevada. Scale at left is index of similarity (Odum, 1971). Numbers give level of similarity for each cluster group. This shows the clustering of coral assemblages of similar ages and their distinction from others.

The Triassic buildups appear to have formed under diverse settings. Most never achieved the continuous regional distribution envisioned by Smith (1927) but instead were linked with the local tectonic-depositional regimes operating in each area.

The only buildup that provides much evidence for a large reef structure is in the Martin Bridge Formation of the northern Wallowa Mountains, Oregon (Nolf, 1966). Unfortunately, this thick, massive limestone sequence is completely recrystallized and yields no paleontologic information. However, it is a large limestone mass that thickens and thins and has abrupt facies changes with other rock types. Such relationships are characteristic of stratigraphic reefs (Fig. 3). Possible correlative limestones at Lake Shasta, California, contain a coral fauna associated with better preserved shallow-water carbonates; however, the corals do not appear to produce a framework structure in the limestone. Older (Ladinian) corals at New Pass, Nevada, occur in similar types of limestones that also clearly indicate shallow-water deposition.

Some limestone of the Luning Formation in the Pilot Mountains of Nevada contains textural features indicative of shallow-water deposition (i.e., oolites, algae-coated grains), but the thin, biostromal coral limestone units in the lower part of the Luning have features indicative of deposition in quieter environments at depths greater than that normally associated with reefs. They lack algae as well as other textures that indicate shallow-water deposition, and they occur between shale intervals that are devoid of benthonic fossils. These coral faunas occur in thin, patchy buildups and are closely associated with beds containing abundant large oyster and pteriinid bivalves. Higher in the same section, however, more massive dolomite and oolitic limestone of shallow-water origin do contain corals, many of which are conspecific with those occurring in the thin buildups.

Corals occurring in thin patches of impure limestone at Vancouver Island and Gravina Island, Alaska, as well as corals in massive, more pure limestone in Idaho, are all judged to have inhabited relatively shallow-water environments. However, some of these limestones, unlike those at other localities further south, lack any indication

of warm-water deposition such as oolites. Calcareous algae are also rare.

Rocks at Lake Iliamna, Alaska, show the most convincing evidence of deposition in deep water. Dark-gray to black limestone contains an abundant spongiomorph fauna and a low diversity coral fauna. Criteria that suggest deposition in quiet, deeper water are 1) thick sequence of limestone with fine-grained, micritic matrices, which lack any textural features or primary structures indicative of shallow-water sedimentation (*i.e.,* oolites, algal laminations, mudcracks, intraclastic grainstone fabrics); 2) poor sorting of fragments and abundance of benthonic organisms *in situ* showing little or no abrasion, as would be expected from wave action, and little evidence of framework destruction except by minor bioerosion; 3) association with dark organic limestones, possibly indicative of euxinic conditions; 4) absence or scarcity of algae; 5) association with planktonic faunas (*e.g.,* halobiid bivalves, *Heterastridium*) that did not inhabit the same environment; 6) apparent lateral relationships with presumably deepwater radiolarian cherts. Although based primarily on negative evidence, all criteria taken together strongly suggest deeper water. Heckel (1974, p. 131) stated that the lack of algae alone is one of the best indications of deepwater buildups.

Cold and deepwater coral banks.—The presence of richly coralliferous carbonate accumulations in cold or deepwater regions has been known for over half a century but has been largely overlooked by geologists. Teichert (1958) presented details of modern cold or deepwater coral banks in the North Atlantic and off the coast of Norway. His paper has became a classic reference on the subject because it alerted both stratigraphers and paleobiologists to the fact that deepwater coral buildups in the rock record could be easily mistaken for warm, shallow-water reefs. The Holocene buildups discussed by Teichert occur at high altitudes in deep fiords of Norway and on the continental slope in the northeast Atlantic. Some appear to occupy the tops of submarine volcanos. These buildups occur at depths well below 90 m (many as deep as 2,500 m) and in water temperatures as low as 4° C. They are dominated by an abundant fauna of both solitary and colonial ahermatypic corals as well as hydrozoans. These coelenterates, together with sponges, bryozoans, brachiopods, mollusks, crustaceans, polychaetes, and echinoderms, build carbonate structures up to 62 m thick and as much as 2.4 km long. The resulting biological and physical environment is one not normally expected at these depths and would be difficult to distinguish from shallow-water patch reefs if present in rock strata.

According to Teichert (1958, p. 1073), some criteria one might use to distinguish these buildups from their shallow-water counterparts are lenticular shape, small size, patchy distribution, paucity of algae, lack of wave erosion with framework breakdown solely by bioerosion, frequent signs of rapid exterminations and reestablishment, the presence of nektonic and open water planktonic faunas, and low diversity of the coral fauna with only a few species contributing to the framework structure.

Since publication of the paper by Teichert, numerous other living deepwater coral buildups have become known in various parts of the world (Heckel, 1974, p. 119), including near Ireland, France, Spain, South Carolina, the Bahamas, the Gulf of Mexico, New Zealand, and Nigeria. Most recently, Neumann, Kofoed, and Keller (1977) reported deepwater buildups that they called lithoherms in the Straits of Florida. It appears that living deepwater buildups are fairly common and no doubt will become better known as exploration of deep marine environments continues.

Corals in the deepwater buildups today are exclusively ahermatypic species that lack a symbiotic relationship with algae. Symbiotic algae (zooxanthellae) in the tissue of hermatypic species have been found to be of significant value to the coral in the removal of nitrogenous wastes. Presence of the algae is also known to greatly increase calcification rates, enabling rapid colony growth. These factors have been cited to explain the domination of hermatypic species over ahermatypic species in the shallow-reef environment. Thus, by virtue of their symbiosis with algae, hermatypic corals have built thick, extensive reef complexes. The relationship between corals and algae does not appear to follow phylogenetic pathways in that it occurs almost randomly within various scleractinian coral taxa, at the familial and even generic or specific levels. Hermatypic corals, due to requirements of the algal symbionts, are limited to warm, shallow, well-lighted environments. They usually do not occur deeper than 70 m and are best developed at 10 m or less. Because the associated algae leave no fossil record, it is not possible to recognize ancient hermatypic corals when living species are not available for comparison. Nevertheless, it is generally thought that this symbiotic relationship arose early in the history of scleractinian corals sometime during the Triassic. According to Wells (1956), however, the oldest ahermatypes extend back only to the Jurassic.

Despite wide knowledge of the stratigraphic distribution of organic buildups, only a few ancient examples are known (Heckel, 1974). An excellent one is a Tertiary buildup described by Squires (1964). Coates and Kauffman (1973) have also described a deepwater coral buildup in the Cretaceous of New Mexico, which they refer to as a coral thicket. The fact that few occurrences are known from the fossil record is not unusual, especially in respect to new awareness of plate tectonics, sea-

floor spreading, and subduction. If ancient examples are preserved, the place to look for them would be in folded mountain ranges such as the Cordilleran region of western North America, where portions of the deep-sea sedimentary record have been brought to the surface. Such examples appear to be present in the Triassic of North America.

As previously discussed, evidence in the Triassic coral buildups of this study suggests that some developed in deep water. If so, then these examples were probably inhabited by ahermatypic corals.

In this study, the occurrence of identical species of scleractinian corals in both deep and shallow environments appears to be especially significant. Either these early coral species had a very sporadic association with algae, being both hermatypic and ahermatypic, a condition not known today, or they were mostly, if not entirely, ahermatypic.

Although many of the Triassic coral species studied may be regarded as massive colonial forms comparable to living hermatypic reef-corals, some differences are clear. Living, light-adapted hermatypic reef corals produce large branching and massive colonies with lateral growth dimensions approaching a meter. In contrast, the Triassic corals are usually small, with dimensions of only a few tens of centimeters (see appendices A through F and Plates 1 to 4). Much current research has been devoted to illustrating how closely living hermatypic coral growth forms are adapted to light dispersion and, consequently, depth (Barnes, 1973; Baker and Weber, 1975; Graus, 1977). To some extent this is believed to be reflected in living coral reef zonation. Corals in the present study show little diversity in growth forms. Such Triassic colonial, compound corals as *Elysastraea, Actinastraea,* and *Thamnasteria* from different deposits indicating shallow and deepwater environments have almost identical growth forms consisting mostly of irregularly incrusting to flat, to only slightly convex, platy shapes. Rarely if ever do any of the massive colonies exhibit tendencies toward the large hemispherical growth so characteristic of modern, shallow-water light-adapted hermatypic species. Also, the branching "*Thecosmilia*" colonies are fragile, dendritic or phaceloid types that seldom show the morphologic plasticity and diversity of form that characterize modern hermatypic species. In some respects the growth forms of some of the Triassic corals resembles those of Paleozoic rugose species.

If Triassic corals are mostly ahermatypic, one might expect them to show close similarities in both organization and growth form with living ahermatypes. Because more than 200 million years of evolution separate these early scleractinians from modern counterparts, it is difficult to make direct comparisons with species, genera, or even families. Also, as pointed out above, the symbiotic condition of living ahermatypes does not appear to follow any obvious phylogenetic pathways. Nevertheless, obvious differences exist when considering solitary vs. colonial life habits. According to Wells (1956) living ahermatypic genera may equal or exceed hermatypes in diversity, but only one-third of all living ahermatypes are colonial. Most are small and solitary. In contrast, the Triassic buildups contain very few solitary corals and colonial forms predominate. According to Teichert (1958) and Squires (1964), however, the Holocene and Tertiary deepwater ahermatypes that build framework structures are exclusively colonial. Branching, dendritic growth forms are particularly abundant.

Judging by morphologic similarity of growth forms, some remarkable similarities exist between some living ahermatypes and some Triassic taxa. The ubiquitous, bifurcating "*Thecosmilia*" colonies (Pl. 2, figs. 3, 5, 7), abundant in presumed deepwater buildups at Iliamna, are similar in growth form to living deepwater oculinids as well as to deepwater Cretaceous framework species described by Coates and Kauffman (1973).

Wells (1956) suggested that the earlier scleractinians in the Middle Triassic were hermatypic, and that ahermatypic forms did not appear until the Jurassic; however, there is little objective evidence for this. Indeed, Teichert (1958) suggested that deepwater ahermatypic corals extend back to the Triassic. From the record of reef-building, Middle Triassic to early Late Triassic corals of the Alpine region were not conspicuous or abundant elements in shallow-water reef environments. Also, from evidence in Alpine regions, scleractinians did not actually construct any significant reeflike structures until the latest Triassic or early Jurassic (Wilson, 1975). Wells (1956) pointed out that known Jurassic ahermatypes appear to show a distinct trend of slowly spreading into colder and deeper water environments through the Jurassic and into the Cretaceous.

If we assume, as the North American coral buildups suggest, that an ahermatypic life style was gradually developed toward the end of the Triassic, movement of ahermatypes into cold and deepwater environments acquires special significance. It suggests that newly emerging reef-building hermatypes that were well adapted for warm, shallow environments were gradually competing with the remaining hermatypes and forcing them into regions of colder or deeper water. Thus, when we attempt direct comparisons between Triassic ahermatypes, which may have inhabited shallow-water environments virtually without competition, and living ahermatypes, which became acclimated to cold and deepwater environments over the course of several hundred million years, we might expect to find major differences in coloniality and growth strategies.

Biologic zonation and paleoecologic relationships.— Buildups at Mina, Black Marble Quarry, Idaho, Vancouver Island, and Gravina Island all contain evidence of organic framework-building by the corals and spongiomorphs. All other localities lack any evidence of framework, although most contain the same coelenterate species.

Within some buildups that display framework structure, vertical zonation is evident in the composition and growth forms of the coelenterates. This is most obvious at the Mina locality in the Pilot Mountains, Nevada (Fig. 5), but it is also present at Vancouver Island and Gravina Island. In vertical sections, a lower zone is dominated by abundant flat, platy colonial corals such as *Actinastraea,* platy, disc-shaped *Thamnasteria* (Pl. 2, fig. 1), and sheetlike incrusting corals such as *Elysastraea* (Pl. 3, fig. 6). This zone is succeeded by another zone characterized by clusters or thickets dominated almost exclusively by large branching corals of the genus "*Thecosmilia*" (Fig. 8A). Overlying the "*Thecosmilia*" zone and culminating the buildups is another zone consisting of molluskan beds dominated by abundant bivalves and few coelenterates (Pl. 9, fig. 6). In the Pilot Mountains the patchlike buildups occur directly above shale sequences and the bases of the buildups are characterized by a unique calcisponge fauna (Fig. 6D, E; Pl. 7) that undoubtedly stabilized the fine-grained, mud substrate and provided a hard substrate for the coelenterates to become established. Nowhere else is that type of sponge fauna evident. At Vancouver and Gravina Islands, the buildups developed within a thick sequence of limestone where the substrate consisted largely of molluskan skeletal debris.

From its position within the vertical sequence, "*Thecosmilia*" appears to have thrived in the upper portions of the buildups. Although this coral occurs with other corals, it does achieve maximum abundance toward the top. None of the basically lenticular buildups are thought to have developed much elevation, but detailed stratigraphic studies in the Pilot Mountains have revealed that some of the patchlike masses locally achieved as much as a 3 or 4 m relief above the sea floor (Fig. 5). The development of the "*Thecosmilia*" zone may have coincided with that stage in the development of the buildups in which slight elevation was acquired, suggesting also that these corals developed best under low sedimentation rates, clear water, and conditions of maximum current flow.

Some modern deepwater buildups termed lithoherms (Neumann, Kofoed, & Keller, 1977) contain branching corals such as *Lophelia* that are remarkably similar to some species of "*Thecosmilia.*" These corals were always observed on the crests or tops of the low-relief buildups. J. C. Land (pers. commun., 1977) suggested that distribution on the buildups is directly related to current velocity and direction.

Major differences in ecologic relationships are most apparent when comparing the Triassic buildups with modern reefs. These include 1) size and morphologic variability of the framework-building coral colonies, 2) diversity and abundance of the coral species, 3) bioerosion, and 4) algae. One of the obvious differences is in the size of the coral colonies. With the exception of "*Thecosmilia,*" which can reach up to a meter in width, most of the Triassic corals are quite small (Pl. 1 to 4), much smaller than living hermatypic reef species. The most common taxa are usually flat and platelike (*Thamnasteria, Actinastraea*) or thin and incrusting (*Elysastraea*), and they rarely develop strongly hemispherical colonies. Generally, corals in the Triassic buildups do not show the great variety of growth forms that characterize modern reef species. Species diversity in the coral buildups is generally low in comparison with that in the modern reef. Although the Mina locality yielded a total of 22 species, the diversity at other localities was much lower (2 to 13 species). It is clear that even where diversity is high, only a few coral species are volumetrically important. At all localities only two or three species are the principal framework-builders. At most localities, species of *Actinastraea* or *Thamnasteria, Palaeastraea* or *Elysastraea,* and "*Thecosmilia*" produce the chief framework of the buildups and are usually supplemented by other corals and spongiomorphs. In such localities as the Black Marble Quarry, Oregon, and Iliamna, Alaska, one or two species of spongiomorphs provide the principal framework.

Another distinguishing feature of the Triassic buildups is the paucity of borings and other evidence of bioerosion. Although some evidence is present (Fig. 6F; Pl. 9, fig. 9) it is not nearly so intense as in modern tropical reefs. Also, there is a general lack of skeletal debris such as flanking beds or broken coral fragments in the lenticular Triassic buildups, perhaps reflecting the absence of physical destruction and comparatively low rates of biologic breakdown. This is in contrast to Triassic reefs of the Alps where bioerosion is interpreted to have also been intense (Zankl, 1971). Also in contrast to modern reefs, calcareous algae are not very abundant in the Triassic buildups. Alpine Triassic reefs differ by containing abundant calcareous green and red algae, which are frequently major contributors to the limestone (Ohlen, 1959; Zankl, 1969). Much of this evidence suggests that the Triassic buildups of North America did not develop in the warm, tropical settings that characterize reefs today and that appear to have been present in the Triassic Alpine regions. A general summary of attributes of the Triassic buildups of North America is given in Table 13.

TABLE 13.—*Triassic Buildups of North America—Summary.*

ATTRIBUTES	LOCALITY								
	Mina	New Pass	California	Oregon, Black Marble Quarry	Oregon, Other Localities	Idaho	Vancouver	Gravina	Iliamna
Dominant groups									
1) 1st order	1) corals	1) mollusks	1) corals	1) spongiomorphs	1) corals	1) corals	1) corals	1) corals	1) spongiomorphs
2) 2nd order	2) spongiomorphs	2) corals	2) spongiomorphs	2) corals	2) spongiomorphs	2) mollusks	2) mollusks	2) spongiomorphs	2) corals
Coral fauna diversity (no. species)	22	5	8	2	5	12	13	10	10
Organic framework	yes	no	?yes	yes	no	yes	yes	yes	no
Biologic zonation evident	yes	no	no	?	no	?	yes	yes	no
Shape of buildups	thin, lenticular bodies, laterally extensive	bank; no apparent shape	bank; thin lenticular bodies	small lenticular bodies	thick ?bank or ?reef	small lenticular bodies	patchlike, small lenticular bodies	patchlike, small lenticular bodies	?bank; no apparent shape
Predominant lithofacies	framestone-bindstone	packstone-grainstone	varied	wackestone packstone framestone	largely recrystallized	framestone	framestone-bindstone	bindstone-framestone	bindstone
Inferred water depth	shallow to deeper	shallow	shallow	?deep	shallow	shallow	shallow	shallow	deep
Calcareous algae	rare	common	rare	absent	?	?	common	absent	rare
Tectonic-depositional setting	nearshore-offshore fluctuating	stable-carbonate bank	stable-carbonate bank	?stable-carbonate bank	stable-carbonate bank	?stable-carbonate bank	active-volcanic	active-volcanic	active-volcanic
Age	early Norian	Ladinian	early Norian	Karnian	early Norian	?late Norian	late Norian	early Norian	late Norian

PALEOBIOGEOGRAPHY AND DISTRIBUTION OF THE CORALS

Dispersal and migration routes.—The similarity between Late Triassic coral faunas of western North America and southern Europe has been noted by various workers beginning with Smith (1927), who addressed himself to the problem of biogeography. Because of these similarities, Smith considered the corals to have considerable biostratigraphic value. The oldest Triassic scleractinian corals appeared in the early Middle Triassic (Anisian) in the German Muschelkalk. Since Anisian age marine rocks in western North America lack coral faunas, European scleractinians appear to have migrated to North America soon after this time. The oldest North American coral fauna occurs at the New Pass locality and is of Middle Triassic (Ladinian) age. This fauna shows differences from that of the younger Triassic localities in North America and contains some species that are known from Europe.

Ammonoids, pseudoplanktonic halobiid bivalves, and planktonic coelenterates such as *Heterastridium* (Pl. 6, figs. 8, 9) are conspecific or very similar with those of Europe and have been used to establish correlations between the two regions (Tozer, 1967; Silberling & Tozer, 1968). The present study has established an even greater degree of similarity between coelenterate faunas of North America and those of the Alpine region in southern Europe. Of the 57 coral and hydrozoan species identified (Table 11) 39 are conspecific with European forms. Of the 43 coral species, 30 are conspecific with European forms. Thus nearly 70% of the coelenterate fauna bears close affinities with those of the Tethyan realm. Although all groups have not yet been studied in sufficient detail, it seems clear that such high levels of similarity do not exist for noncoelenterate benthonic invertebrates. Smith (1927) listed few benthonic invertebrates, with the exception of the corals, which have affinities outside North America.

Smith (1927) postulated that during the Triassic a marine connection extended from the Tethys region of the Mediterranean through the Gulf of Mexico to western North America. Presently, accepted continental reconstructions for the Triassic suggest that North America was still part of Pangea and that by the Late Triassic the fragmentation of Gondwanaland had just begun. No Triassic marine rocks are known in eastern North America. The interpretation of eastern North America and western Europe as land areas characterized by continental sedimentation casts doubt on the existence of a westward marine connection from the Tethys region to western North America. Olson and Leyden (1973, p. 724) presented a paleogeographic map showing that until the Late Triassic, the Gulf Coast was an evaporite basin, completely isolated from the Pacific Ocean. Tozer (1971, p. 1007), however, stated that the distribution of one Middle Triassic ammonoid species suggests the possibility of a westward connection between the western Tethys and North America. Such a connection, if ever present, must have been through the embryonic Atlantic Ocean and continued across the Gulf of Mexico. In the face of such meager data, a migration route for Triassic corals from the Tethys to western North America via a westward route must therefore remain doubtful. The most logical route from the Tethys would be eastward across the Tethys via the Pacific Ocean.

Latitudinal distributions and climate.—At present, marine Triassic rocks are distributed in the circum-Pacific, Arctic, and Tethys regions (Tozer, 1971; Fig. 1). As expected, most of the Late Triassic pelagic faunas appear to have been especially cosmopolitan. The distribution of Triassic corals is confined to the Cordilleran region and runs generally north-south from Alaska to Peru and occurs within the latitudinal range of 60° north to 12° south (Fig. 1). Latitudes in presently accepted Late Triassic continental reconstructions do not differ significantly from those of today. Occurrences of coral faunas in the Tethys region are restricted to an east-west belt (Fig. 1) and in Triassic reconstructions are aligned closely to the equator, presumably within a warm tropical region just north or south of the equator. While the latitudinal distribution of the Tethys is generally compatible with the distribution of modern hermatypic reef corals, those of the Cordilleran region produce an anomalous pattern. This has also been pointed out by Tozer (1970) in discussing Late Triassic reef faunas at high latitudes in the Canadian Cordillera.

Unlike the pelagic faunas, the noncoelenterate benthonic reef invertebrates of North America form a distinct zoogeographic province. We are thus faced with dual problems—the close similarities of the North American Triassic coral faunas with those in distant areas such as the Alps and the anomalous presence of these faunas in North America at unusually high latitudes in both present-day and Triassic continental arrangements.

Much evidence indicates that Triassic climate was warmer and more uniform than today (Schwarzbach, 1963) with arid conditions in some areas. On the other hand, Gordon (1973, 1976) has indicated that many marine groups in the Late Triassic show distinct latitudinal differentiation into boreal and tropical regions, undoubtedly related to the effects of temperature. Triassic plants also show evidence of differentiation into polar and equatorial belts (Barnard, 1973), suggesting climatic control. Thus, although the climate may have been warmer, it was probably not entirely uniform, but differentiated latitudinally with marked seasonal variations.

The influence of oceanic currents along the coast of

North America is difficult to assess but, as suggested by Valentine and Moores (1973), a southward-flowing boreal current may have existed along the western margin of North America during the Triassic. Like present currents, this may have produced cool water temperatures at relatively low latitudes. Given the generally north-south trending distribution of the coral faunas of western North America, one would expect to find the most active reef building in the southern regions. Thick limestone buildups do occur in Oregon and northern California. The thick Martin Bridge Formation of Oregon (Nolf, 1966) may contain the Triassic buildup most similar to Alpine examples. The buildup in Oregon is elongated northeast to southwest, paralleling the Triassic continental margin with Triassic paleolatitudes approximately equivalent to those of the Tethys region (Smith, Briden, & Drewry, 1973, fig. 9).

Hypotheses relating to plate tectonics.—In the present study two major paleobiogeographic problems have been discussed: the wide latitudinal distribution of the coral buildups, and the presence of cosmopolitan coral faunas in western North America in association with other invertebrate groups that are largely endemic.

Several tectonic hypotheses were outlined earlier and have direct bearing on the paleobiogeography and dispersal of the corals. Hypotheses relating to plate history can be discussed in terms of two concepts. The first suggests that the coral buildups of the Cordilleran region represent fragments of Asia, some Pacific continent, or a multitude of fragments that have been carried across the Pacific and sutured to North America (Wilson, 1968; Danner, 1970; Hughes, 1975; Nur & Ben-Avraham, 1977). While this hypothesis might explain the presence of corals with Tethyan affinities, it does not explain the distribution of the other North American Triassic benthonic invertebrates that form a rather distinct zoogeographic province.

The second tectonic hypothesis suggests that large fragments of diverse terranes along the northwest Pacific coast were accreted to North America after rifting during the Triassic. According to this hypothesis, since the Late Triassic these terranes have undergone extensive northward movement along large-scale, left-lateral transform faults (Jones, Silberling, & Hillhouse, 1977). This terrane is generally identified by similarities in Triassic stratigraphy. According to this hypothesis, anomalous, high latitude, tropical coral buildups are explained as originally low latitude structures that have been displaced northward. Exact amounts of displacement and timing of the movements are unknown, but presumably thousands of kilometers of displacement are required.

While this hypothesis is appealing because it explains the wide latitudinal distribution of coral buildups, many unresolved issues remain, such as the cosmopolitan nature of the coelenterates but the largely endemic nature of the noncoelenterate, benthonic invertebrates. Also, it is not clear how all of the coral buildups fit into this tectonic hypothesis. Only two of the buildups, those at Vancouver Island and Oregon, lie within the proposed fragment of Wrangellia. The locality at Iliamna, Alaska, is much further north and lies outboard of Wrangellia whereas the Gravina Island, Alaska, locality is inboard of this terrane. It is also unclear how the buildups further south relate to Wrangellia. Most advocates of this hypothesis presume that all regions along western North America are in fact fragments of other terranes similar to Wrangellia and that since the Triassic, each has been displaced from its original location. While the basic assumptions of this hypothesis have merit, the absence of detailed data on the timing, amount of movement, and relationships of the various terranes make it difficult to apply as a working hypothesis.

New hypothesis.—I propose an alternative hypothesis based on the paleoecological implications of corals. The basic assumption is that most if not all of the corals in the buildups are ahermatypic. This assumption provides an explanation for the anomalous occurrences at high latitudes and the cosmopolitan nature of the corals. Unlike hermatypic reef corals, ahermatypes have a wide range of depth distributions. They are not unusual today at depths of 1,500 m; to date, the deepest authenticated depth for ahermatypic corals is 6,000 m (Wells, 1956). They can also inhabit shallow depths but seldom construct buildups there. Due to their wide temperature and depth tolerances, ahermatypic corals are fairly cosmopolitan in the oceans today and cannot be separated into distinct faunal provinces (Wells, 1956). Many modern ahermatypic species, such as *Lophelia prolifera* and *Fungiacyathus marenzelleri,* are among the more cosmopolitan invertebrates. The former species inhabits the Caribbean, Mediterranean, Atlantic, and Antarctic; the latter occurs in almost all oceans except the Mediterranean Sea. According to recent research on living ahermatypic corals (Cairns, 1976), the deeper the ahermatypic corals, the more cosmopolitan is their distribution. Although the oceans pose formidable barriers to the dispersal of many shallow-water benthonic invertebrates, including hermatypic corals, bodies of deep water do not present an obstacle to the distribution of many ahermatypic species. Given an ample supply of nutrients and water circulation, these corals can occur at remarkably high latitudes and depths. Today they even build reeflike structures north of the Arctic Circle (Maksimova, 1972). By comparison with the distribution of living ahermatypic species, the widespread distribution of Triassic "ahermatypes" across expanses of ocean separating the Tethys from western North America seems plausible. This hypothesis explains the distri-

bution pattern of the Triassic corals in a simple and direct manner without evoking complicated processes or proposing unconventional tectonic hypotheses.

A possible parallel exists in the distribution of Cambrian trilobite biofacies described by Cook and Taylor (1975). The similarity of trilobite faunas in eugeosynclinal rocks of western United States with those of Asia and their dissimilarity from typical shelf faunas of western North America was used by some workers to support the contention that rocks of North America are part of an Asian block left behind after a hypothetical collision between the two continents. Cook and Taylor, however, using data on trilobite paleoecology, were able to demonstrate convincingly that Cambrian trilobites were differentiated into shallow-shelf, endemic faunas and cold-water, cosmopolitan faunas. The latter were capable of free migration across the Pacific Ocean between Asia and western North America.

TRIASSIC BUILDUPS OF EUROPE—COMPARISONS WITH NORTH AMERICA

Buildups of Triassic age are best known in Alpine regions of Europe, where they occur in thick sequences of dolomite and limestone. For almost a century carbonate rocks in this classic region have been recognized as reefs and have received much study. Due to tectonic and structural relationships, the buildups of this region are divided into two parts, the Northern Limestone Alps of Germany and Austria and the Southern Alpine Triassic or Dolomites of northern Italy.

Major stratigraphic problems exist in defining the Triassic Alpine stratotypes (Silberling & Tozer, 1968), and boundary problems in the Norian and Rhaetian are still unresolved (Zapfe, 1967). Nevertheless, carbonate buildups of the Alps are considered to range from the Ladinian through the Rhaetian stages, and in the Northern Limestone Alps they continue into the Lower Jurassic.

TRIASSIC BUILDUPS OF THE ALPS

The Dolomites are over 2,000 m thick and contain a succession of reef limestone ranging in age from Middle to Late Triassic. Frequently these are associated with great volumes of volcaniclastic material. Although Middle Triassic sequences in the Dolomites have been referred to as reefs, they have little reef framework and corals are minor constituents. Because of the lack of framework structure, they are best categorized as a complex of carbonate banks (Wilson, 1975). Much of the sequence is highly dolomitized and contains abundant dasycladacean algae, sponges, and mollusks, along with other invertebrates. Corals are only locally abundant. In the Northern Limestone Alps, other Middle Triassic buildups have been referred to as banks. One of these, the Middle Triassic Wetterstein Limestone, contains a diverse assemblage of invertebrates and calcareous algae, including corals. It grades from shallow-water facies to deeper downslope mud accumulations. Based on a lack of reef framework structures, the presence of similar types of faunas, and generally similar tectonic settings, Wilson (1975) compared the Middle Triassic banks of Europe to the Upper Permian "reef" complex of west Texas.

Upper Triassic buildups are best preserved in the Northern Limestone Alps of Austria and Bavaria. Massive limestone that characterizes these areas ranges from Norian to Rhaetian in age and extends along strike in an east-west direction for over 500 km. It is best preserved along the southern margin of the Northern Limestone Alps from the vicinity of Vienna to Lofer. Limestone sequences approximately 1,200 m thick are present in this area as well as corals in framework structures.

Well-studied reefs of Norian to Rhaetian age in the Dachstein Limestone near Berchtesgaden were recently described in detail by Zankl (1969, 1971). Most of the reef limestone is undolomitized and contains abundant framework-building corals. Forereef, central reef, and backreef facies developed on shallow platforms that Wilson (1975) termed reef-lined banks.

One reef in Bavaria, the Hohe Göll, is perhaps the best documented example. Zankl (1967, 1969) has shown that it is actually a series of small, superimposed patch reefs and not a massive reef as once thought. Each patch reef is about 5 m in diameter and 10 cm to 2 m in height. Quantitative study (Zankl, 1969), has shown that the proportion of reef framework to debris is only 1 : 9. Corals, sponges, calcareous algae, and foraminifers are abundant, and sponges and corals occur in equal proportions. Species of *"Thecosmilia," Astraeomorpha, Thamnasteria, "Montlivaltia,"* and *Palaeastraea* identical to those of North America characterize the limestone. Zankl (1969) distinguished high growth forms represented by branching phaceloid corals such as *"Thecosmilia"* and *Oppelismilia* and low growth forms typified by such incrusting corals as *Thamnasteria* and *Elysastraea.*

Twenty-four species of corals were illustrated by Zankl (1969), of which 12 are known also in North America. In addition, diverse foraminifers, sponges,

spongiomorphs, bryozoans (more probably sclerosponges or hydrozoans), brachiopods, bivalves, gastropods, cephalopods, crustaceans, echinoderms, fish, and calcareous algae are present. In these Dachstein reefs, "*Thecosmilia*" characterizes the more protected, quieter facies and basinal facies. Multiple cycles of cementation and framework growth characterize the patch reefs. According to Zankl (1971), these patch reefs contributed an abundant supply of detritus, which was lithified by early diagenetic cement. The process resulted in the formation of an impressive thickness of limestone that resembles a massive reef.

Interfingering with the Dachstein Limestone are the Zlambach beds that represent deeper water Hallstatt facies (Zankl, 1971). The Zlambach rocks are Norian to Rhaetian in age and consist mostly of dark shaly marls and dark bioclastic limestone. The Zlambach has many coral species in common with North America. According to Zankl (1971), the Zlambach beds were deposited in deeper, calmer waters away from the shallow-shelf environment.

Younger reef limestone sequences of the Dachstein occur in the Northern Limestone Alps and span the Triassic-Jurassic boundary. The upper or Rhaeto-Liassic portion of the Dachstein is characterized by thick, massive limestone with well-developed coral framework. One of these, the well-known Steinplatte-Sonnenwänd complex near Lofer, Austria, was studied by Ohlen (1959). This reef complex bordered the deeper water Kössen Basin. It is estimated that during its formation, the edge of the complex attained relief of 160 m. Corals of the reef facies are described by Ohlen (1959). Only nine species are present in the entire complex, and only four of these are found in North America. Ohlen stated that the framework reef facies was built exclusively by a single species of "*Thecosmilia*" that produced gigantic colonies up to 10 m high. Some of the species in the Rhaetian portion of the reef complex show radical modifications in growth form, which are thought to be related to depth and water turbulence. The corals are associated with particularly abundant and diverse associations of calcareous algae and foraminifers in addition to ?bryozoans, brachiopods, mollusks, arthropods, echinoderms, and problematica.

Thick limestone of the Steinplatte has long been regarded as a massive reef, and Ohlen (1959) referred to the framework nature of reef facies. A. G. Fischer (pers. commun., 1975), however, has discovered that the apparently massive reef is actually numerous, small, tabular bodies that grade laterally into calcarenite facies. Thus, like the older Hohe Göll (Zankl, 1969), the massive Steinplatte reef may also be a series of small patch reefs with vast quantities of cemented debris.

During development of the marginal Rhaetian reefs, small bioherms containing corals and other reef organisms existed in the deeper water of the Kössen Basin. The Kössen Beds are characterized by marl, shale, and limestone. Much of this unit is dark bituminous limestone and shale with significant amounts of pyrite. The Kössen beds described by Ohlen (1959) are sandwiched between thicker shale and marl, and the limestone had a strong fetid odor when broken, possibly indicating the presence of organic matter.

The Kössen beds are thought to have been deposited in deep euxinic basins that bordered the reefs. The limestone bioherms reach large sizes and are characterized by corals and other reef organisms. According to Zankl (1971) the coral limestone is dark and thin-bedded and occurs as lenses up to 10 m thick. "*Thecosmilia*" sp., *Thamnasteria norica, Actinastraea* sp., and other corals identical to species in North America are present. Abundant bivalves (*Pteria, Myophoria, Ostrea,* and *Pecten*) and some foraminifers occur in the Kössen beds. Spiriferid brachiopods are especially abundant in some beds. Terebratulids and crinoids are also present. "*Thecosmilia*" is the most abundant coral in most bioherms, which are of special interest because they appear to be deepwater structures comparable to those of North America.

The absolute depth of the basins is difficult to estimate, but based on the relief of the shelf-edge reef, a minimum depth of 100 m is indicated (Wilson, 1975). It should be noted that this depth is well below that of shallow reefs today and also below the maximum depth of most algae. Why the corals built reefoid masses in this type of environment has not been satisfactorily explained. Some coral bioherms in the Kössen beds appear to have developed on piles of bivalve shells that provided an initial hard substrate.

COMPARISONS WITH NORTH AMERICA

Most Triassic coral buildups in North America are laterally restricted and usually are only a few meters thick whereas Alpine reefs occur in vast carbonate complexes, some of which are more than 1,200 m thick. As mentioned, several of the better known Alpine reef sequences have been reexamined and found to be series of thin, laterally restricted patchlike buildups, which in size and shape are more comparable to the buildups of North America.

In general, the composition and diversity levels of the Alpine coelenterate faunas are similar to those of North America. In the Steinplatte reef, colonies of "*Thecosmilia*" dominate the sequence and reach sizes considerably larger than in North America, but judging from drawings by Zankl (1969), the sizes and growth forms of individual corals are not unlike those of North America. Why, then, did the coral buildups of North

America not reach the scale and magnitude of reef sequences in the Alps?

During the Triassic, prolific coral growth in the Tethys may have been related to a combination of climate, diagenetic cementation, and tectonic setting. The reef complexes of the Northern Limestone Alps developed on a fragmented continental margin, which under tensional and perhaps directional stress, produced horst and graben style tectonics (Wilson, 1975), resulting in rapid subsidence and uplift of the carbonate platforms. In such a tectonic setting, warm circulating water in the Tethys Ocean appears to have promoted rapid growth of small patch reefs. The warm, perhaps arid, climate may have also facilitated early diagenetic cementation of the reefs as shown by Zankl (1969) and suggested by Wilson (1975). Influx of terrigenous clastics appears to have been at a minimum in the area, permitting thick accumulations of massive carbonates.

From discussions of reefs in the Berchtesgaden Alps by Zankl (1969, 1971), it is clear that the volume of the reef debris overwhelmingly exceeds the organic framework represented by the small patch reefs. I suggest that the Alpine corals were incapable of building massive and extensive large-scale framework structures, even in the warm tropical setting of the Tethys, because of their slow growth rates coupled with the high rates of framework destruction. The effects of early cementation may have been a principal factor in promoting rapid vertical growth.

Clearly the Triassic buildups of North America did not develop under the influence of the same types of tectonic forces as did those of the Alpine region. In North America the buildups appear to have developed on either relatively stable carbonate platforms or in active volcanic arc settings (Table 13). The coral faunas in North America may also have developed in cooler, more seasonal climates than those of the Alps, which may have inhibited coral growth and early diagenetic cementation. As previously pointed out, a distinctive attribute of most North American buildups is the paucity of algae, especially as sediment contributors. In the Alpine reef complexes, the abundance and diversity of calcareous algae indicate a warm and uniform climate.

Finally, a similarity does exist between buildups of North America and the Alpine regions in that both show evidence of deeper water coral structures. In North America, evidence of deeper water buildups has been found in Nevada, Oregon, and Alaska (Table 13) whereas in the Alps similar examples may exist in the Hallstatt Facies and the Kössen beds. After examining some of my thin sections and fossils, Zankl (pers. commun., 1977) remarked that especially noteworthy similarities appear to exist between the Iliamna locality and the Alpine Kössen beds. In composition and framework construction, parallels may also exist between the Kössen beds and thin-bedded lenticular buildups of the Pilot Mountains near Mina, Nevada.

If most or all Triassic corals of North America are ahermatypic, as this study indicates, then identical species in the Alps most likely followed this lifestyle also. The youngest and best-represented Triassic buildups in North America are Norian in age. The Rhaetian is poorly represented in North America, and in most sequences where sedimentation appears to have been continuous between the latest Triassic and the Jurassic, noncarbonate rocks predominate with no indications of reefs or buildups. In the Alps, however, coral reef-building was especially active in the Rhaetian. In the Rhaeto-Lias sequence (Zankl, 1971), prolific reef development appears to span the systemic boundary. Perhaps the hermatypic lifestyle was not acquired by scleractinians until the latest Triassic (Rhaetian) or earliest Jurassic. If so, the warm-water setting of the western Tethys may have fostered this early coral-algal symbiosis.

CONCLUSIONS

Reevaluation of the Triassic buildups in western North America has yielded a new and comprehensive body of information on their paleoecology, structure, and developmental history. The general findings are summarized in Table 13.

Two major problems emerge from this study. First is the wide latitudinal distribution of the coral buildups with anomalous occurrence of presumed tropical coral faunas at high latitudes. Second is the presence in western North America of cosmopolitan coral species having strong affinities with distant coral faunas of the Tethys realm. The second problem is compounded by the fact that while the corals are cosmopolitan, the other benthonic invertebrates appear to be largely endemic, producing a rather distinct zoogeographic province in western North America.

To explain these problems I propose a paleoecological hypothesis based on the idea that the early scleractinian corals of the buildups were largely if not entirely ahermatypic. This assumption is derived from a number of independent facts presented in this study: 1) the small size and shape of the coral buildups, clearly unlike most living coral reefs produced by rapid growth of hermatypic corals; 2) the size and growth forms of the

corals, which, with the exception of "*Thecosmilia*," are small and nonmassive, assuming flat, platy or incrusting growth habits distinctly unlike massive, light-adapted Holocene reef corals; 3) the identification of deepwater Triassic buildups containing corals identical to those of contemporaneous shallow-water deposits.

The wide latitudinal distributions, the occurrence of deepwater buildups and the absence or scarcity of algae in some buildups all suggest that the climate may not have been entirely warm and uniform during the Late Triassic. In addition, cool, south-flowing currents may have existed along the continental margin, exerting considerable influence on the distribution of shallow marine invertebrates.

Besides explaining their wide latitudinal distributions, the interpretation of an ahermatypic lifestyle for the corals helps explain their cosmopolitan nature and makes possible the postulation of migration routes between the Tethys and western North America. As exhibited by living deepwater coral species, wide tolerances to both cold temperatures and depth may have aided the Triassic corals in more successful migrations between the Tethys and western North America. An ahermatypic lifestyle may also explain the apparently wide latitudinal distributions of Triassic scleractinians because, like many living ahermatypic species, they were not closely adapted to warm tropical belts. Although Triassic corals undoubtedly colonized many warm, shallow-water environments such as those on carbonate platforms, they were never capable of constructing large-scale reefs.

Warm-water reef sequences in Alpine regions of Europe provide additional insight into the ahermatypic hypothesis. Recent reevaluation of some Late Triassic carbonate reef sequences in the Northern Limestone Alps has revealed that little coral framework is actually present. Some of the massive reef limestone, such as that of the Berchtesgaden Alps, shows that the apparently massive reef sequence is actually composed of numerous small, lenticular, patchlike buildups. The thicknesses and shapes of these appear comparable to those of North America. Also as in North America, certain facies in the Alpine sequences may contain examples of deepwater scleractinians.

It is suggested that the hermatypic condition did not arise in the early scleractinians until the latest Triassic or Jurassic, when corals underwent rapid diversification and undoubted large-scale coral reefs appeared. The warm water, arid conditions of the Tethys may have provided the type of environment that fostered symbiotic associations between algae and scleractinians. The fact that the Triassic buildups of the Tethys developed thick massive carbonate sequences while those in North America did not may be attributed to differences in climate, style of tectonic activities, early diagenetic cementation, and increased rates of physical and biologic breakdown.

In this study the ahermatypic idea is selected as a viable working hypothesis to explain the problems in the most simple and direct manner. A great deal of additional information is still needed including a thorough systematic evaluation of all benthonic Triassic invertebrates of North America and a comparison of the corals with Alpine type species. Since the majority of the buildups investigated in this study are Norian in age, not as much is known about older buildups. Perhaps Ladinian or Karnian occurrences in Alaska and the Canadian Cordillera will also yield new data, permitting more meaningful comparisons with those of Norian age.

Finally, a region in the Cordilleran belt which holds key answers concerning Triassic coral buildups is Peru (Fig. 1). Located east of the Andes, Late Triassic "reef" structures have been only briefly mentioned (Körner, 1937) and virtually nothing is known concerning their shapes, composition, structure, or paleoecology. Because these alleged reefs are the southernmost Triassic buildups known, they hold great potential for further clarification of problems related to Triassic climate, ecology, and biogeography.

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APPENDICES

Units in each locality are described from top to bottom.

APPENDIX A: Measured Sections in the Pilot Mountains, Nevada

Locality *MC*

Unnamed canyon 14.5 km west of Mina. Long. 118°02′45″, Lat. 38°25′55″. Section measured in the lower member of the Luning Formation. Strata measured in an anticlinal limb, dipping 20° southwest. Almost continuous section with one normal fault.

Unit	Description	Thickness (m)
18	Limestone, massive, reefoid; dolomitic, highly recrystallized, abundant massive and branching *"Thecosmilia";* sponges and molluskan debris common; crinoid columnals concentrated in certain beds.	9.1
17	Limestone, fine-grained, crystalline (nonreefoid); with thin incrusting colonial corals and molluskan debris.	1.8
16	Limestone, dolomitic, medium-bedded, coarsely crystalline; with abundant massive corals, molluskan debris, and ?brachiopods; brecciated zones and large clasts up to 2 cm diameter; fossils poorly preserved.	4.6
15	Limestone, fine to coarse-grained, medium to massive-bedded, dark, mostly calcarenite; dolomitic and strongly recrystallized in part; vague traces of branching and massive corals and bivalves; much bioclastic debris with occasional oolitic zones and small scale cross-bedding; some zones of finely laminated limestone.	23.0
14	Shale, light-gray, fissile; rare halobid bivalves and impressions of ammonites; large ichthyosaur vertebrae.	20.6
13	Limestone, dark-gray, fine-grained; composed of a bivalve coquina; minor incrusting corals and spongiomorphs.	4.0
12	Shale, similar to unit below; irregular contact with underlying limestone.	3.6
11	Limestone, reefoid, similar to those below with short bushy colonies of branching *"Thecosmilia"* near top of unit; colonies reach 150 cm in diameter; smaller colonies appear to be developed directly upon larger colonies producing limestone thickenings 1 to 1.5 cm thick.	3.7
10	Shale, light-gray; pyrite crystals common; shale irregularly drapes over limestone below; rare impressions of *?Carnites.*	3.1
9	Limestone, reefoid, fine-grained; with abundant branching, thin incrusting, and massive-platy corals, especially *Actinastraea* and *Thamnasteria;* spongiomorphs common; sponges and numerous bone fragments at base; near top, small heads of branching *"Thecosmilia"* up to 45 cm wide and 30 cm high in life position; massive-platy corals are up to 60 cm in diameter and 12 cm thick and characterize much of unit.	2.7
8	Shale, light-gray, pyrite common; no fossils observed.	2.4
7	Limestone, reefoid, similar to those below; with abundant corals and incrusting spongiomorphs. Incrusting sparse *Ascosymplegma* at base; spiriferid brachiopods clustered within cavities; coral colonies more massive and thicker toward top. Corals incrusting and ribbon-like as well as platy; numerous small convex disc-shaped colonies of *Thamnasteria rectilamellosa;* max diameters 33 cm, max thickness 10 cm.	1.5
6	Shale, light-gray; no fossils observed; grades upward into limestone.	3.1
5	Limestone, dark-gray, thin-bedded, reefoid; pyrite common; framework constructed by abundant incrusting	4.3

and platy corals, spongiomorphs and sponges; grades upward into nonframework, less coralliferous limestone with abundant molluskan (bivalve) hash; rare gastropods; crinoid columnals common in shell bed at top; brachiopods throughout, especially at base; *Thamnasteria* forms massive plates 16 cm in diameter and 5 cm thick; *Actinastraea* large, platy, up to 16 cm in diameter, of comparable thickness and often stacked; occasional *"Montlivaltia"* and abundant thin incrusting corals 5 cm thick; corals show evidence of borings (2 to 5 mm in diameter).

4 Shale, light-gray, fissile. Irregularly overlaps underlying limestone. No macrofossils observed. 2.4

3 Limestone, thin-bedded, fine-grained; with abundant bivalves and some brachiopods. Corals present but no reefoid framework. *Elysastrea* and *Actinastraea* common. 2.1

2 Limestone, dark-gray, reefoid, fine-grained, partly recrystallized; irregularly bedded, dark-brown with light mottling; sharp contact with underlying shale; occasional thin shale partings 1 to 4 cm thick; thin, ribbonlike incrusting corals *Elysastrea* and more massive *Thamnasteria* abundant; spongiomorphs, brachiopods, and bivalves, especially *Ostrea,* abundant; sponges well developed at base; large at base; large bone fragments also at base. 3.1

1 Shale and argillite, silty in part; occasional thin limy beds; megafossils rare (*Tropites, Juvavites*). 20.0

Total thickness of section: 115.1 m.

Locality *DC*

Section measured on the north side of Dunlop Canyon Road in the Pilot Mountains. Long. 118°07′10″, Lat. 38°26′0″. Approximately 5.2 km west of locality *MC*. Section in strata dipping 25-35° SE. Section measured from west to east along road in east limb of overturned anticline. Section cut by thrust fault.

37 Limestone, thin-bedded, bioclastic, alternating with shale; corals, spongiomorphs, brachiopods, and bivalves common. 20.0

36 Limestone, reefoid, thin-bedded; abundant massive and incrusting corals and spongiomorphs similar to those occurring below; much recrystallization. 7.3

35 Limestone, thin-bedded, coralliferous with abundant molluskan-crinoidal debris; brachiopods and some large massive corals; *Actinastraea, Palaeastraea,* and *Elysastraea* common; some large branching spongiomorphs 75 cm wide at top and 45 cm high. 11.0

34 Shale, dark-gray, fissile; no macrofossils observed. 5.8

33 Limestone, rubbly, thin-bedded; abundant *Ostrea* shells and occasional brachiopods. 4.5

32 Limestone, thick-bedded, bioclastic; molluskan and crinoidal debris; small *Isocrinus* columnals and cidarid spines. 4.4

31 Argillaceous interval, partly covered. 3.7

30 Limestone, bioclastic, thin-bedded, incrusting corals, molluskan debris, abundant oysters; occasional branching spongiomorphs and incrusting *Ascosymplegma.* 5.8

29 Mostly covered shaly interval. 3.0

28 Limestone, thin-bedded; corals and abundant *Ostrea* and other small, thick-shelled bivalves. 1.5

27 Shale, gray, no fossils observed. 1.5

26 Limestone, reefoid, medium-bedded; abundant large massive platy corals, branching and incrusting spongiomorphs common; *"Thecosmilia"* present near top form low, bushlike colonies up to 160 cm high; occasional large platy colonies of *Actinastraea* up to 45 cm in diameter and 5 cm thick; abundant ribbonlike irregularly incrusting *Spongiomorpha* and similarly shaped colonies of *Elysastraea; Actinastraea juvavica* common; *Palaeastraea descussata* forms thin, incrusting colonies with small domelike prominences. 6.6

25 Limestone, bioclastic, thin-bedded; with abundant bivalve and brachiopod debris; minor incrusting corals; coral abundance increases upward. 1.2

24 Shale, gray, fissile; macrofossils absent. 3.6

23 Limestone, thin-bedded, bioclastic; with common incrusting corals and molluskan debris. 6.1

22 Covered interval poorly exposed, appears to be alternating shale and limestone. 19.0

21 Limestone, dark-gray, argillaceous, with thin shale partings; brachiopods and oysters common. 1.8

20 Limestone, bioclastic, rubbly, thin-bedded; abundant molluskan debris with occasional brachiopods. 20.4

19 Shale, dark-gray; no macrofossils apparent. 4.4

18 Limestone, thin-bedded, rubbly; with abundant bivalve debris; brachiopods common. 4.4

17 Shale, silty, dark-gray; no macrofossils apparent. 5.8

(Thickness subtotal: 141.8 m)

—thrust fault contact—

16 Limestone, bioclastic, coralliferous, recrystallized with abundant molluskan debris. 10.2

15 Shale, gray, fissile; with rare *Halobia* impressions. 3.7

14 Limestone, fine to coarse-grained, argillaceous; bivalve shells abundant with *Ostrea;* brachiopods common, corals rare; more argillaceous toward top. 23.3

13 Shale, fissile, light-gray, calcareous. 3.7

12 Limestone, thin-bedded, reefoid, bioclastic with abundant corals *Actinastraea* and *Thamnasteria.* Large fragments of bivalve *Trichites;* platy *Thamnasteria* 15 cm in diameter, 3 cm thick, other massive corals averaging 8 cm diameter, 2 cm thick; *Elysastraea profunda* irregularly incrusting colonies 7 cm diameter, 2 cm thick; *Actinastraea* (platy) 21 cm in diameter, 2.5 cm thick. 4.0

11 Shale, silty, calcareous, brown and rubbly. Thin bioclastic limestone at top; no fossils observed. 5.7

10 Limestone, thin-bedded, fine-grained; with abundant oysters *Ostrea* and *Septocarditia;* minor corals. 2.5

9 Shale, light-gray and fissile; no fossils. 5.8

8 Limestone, thin-bedded, bioclastic; with abundant crinoidal debris and brachiopod and bivalve shells, occasional coral fronds. 4.9

7 Limestone, medium-bedded, bioclastic; with abundant corals, brachiopods and molluskan hash; massive *Actinastraea* and *Thamnasteria* common; *Spongiomorpha* present. 5.3

6 Limestone, reefoid, thin, irregularly bedded and fine-grained; large convex massive-platy coral colonies of *Thamnasteria* reaching 80 cm in diameter and 10 cm in thickness; colonies average 17 cm diameter, 5 cm thick; massive *Actinastraea* colonies up to 30 cm in diameter, 1 to 2 cm thick; thinner incrusting colonies of *Elysastraea; "Thecosmilia"* present at top, colonies reach 150 cm in width and 10 cm in height; abundant molluskan debris; corals contain numerous borings 1 to 4 mm diameter; spiriferid brachiopods common in coral cavities. 8.2

5 Limestone, argillaceous. Few fossils evident. 1.0

4 Limestone, reefoid, medium-bedded, fine-grained; abundant massive-platy *Thamnasteria* and thinner colonies of *Elysastraea;* occasional solitary *"Montlivaltia"; spiri-* 3.0

ferid brachiopods and sponges abundant especially at base where large incrusting colonies of *Ascosymplegma* are present; much bivalve debris composed of pectinids and *Septocarditia* as well as crinoid columnals; top of unit composed chiefly of branching *Spongiomorpha dendriformis,* 30 cm high.

3	Shale and limestone alternating; limestone contains abundant *Ostrea* shells as well as brachiopods and other bivalves.	4.0
2	Shale, dark, with lenses of limestone similar to unit below but with more abundant corals and fewer sponges.	4.9
1	Limestone, thin-bedded, 1 to 3 m thick, dark-gray, rubbly, weathering, alternates with thin beds of shale of equal thickness; limestone, calcarenite composed of abundant shells of *Ostrea;* pectinid bivalves and brachiopods common, some small platy corals *Thamnasteria* and many *Isocrinus* columnals.	15.3

(Thickness subtotal: 105.5 m)

Total strata measured: 247.3 m

APPENDIX B: Measured Section at New Pass, Nevada

Section measured near New Pass Mine, New Pass Range, west side of South Canyon (Bull Canyon). Lat. 117°29'31", Long. 39°36' 42". Section steeply dipping 45° SE. Lower member, Augusta Mountain Formation.

Unit	Description	Thickness (m)
12	Argillaceous interval with ammonites and bivalves. Occasional, thin limestone beds 0.1 to 0.3 m thick. Limestone beds fine to coarse-grained and fossiliferous. *Paratrachyceras* and *Halobia* common.	50.0
11	Limestone, coarse-grained, dark-brown, fossiliferous; with aulacoceratid cephalopods and crinoid columnals common.	1.5
10	Limestone, argillaceous, dark, thin to medium-bedded, some shale beds 0.5 m thick. Limestone mottled. Fossils not conspicuous.	10.0
9	Limestone, fine to medium-grained, thin-bedded, with some thin shale beds. Abundant *Solenopora* algal bodies from 0.5 to 1.0 cm diameter. Bivalves and ?ostracodes common. Corals rare.	6.7
8	Limestone, thin-bedded, coralliferous, light-gray, fine to medium-grained. Angular clasts 0.5 to 1 cm in diameter. Abundant flat, platy corals. *Actinastraea* up to 7 cm thick and 45 cm long. Occasional disc-shaped *Thamnastraea* colony; incrusting, ribbonlike corals 0.5 to 1 cm thick, 12 cm length. Largest platy coral colony 75 cm long and 20 cm thick but majority 30 by 10 cm.	5.2
7	Calcarenite, coarse-grained, thin-bedded. Numerous thin shale partings. Abundant platy colonial corals and pectinid bivalves.	4.6
6	Calcarenite, very coarse-grained. Highly fossiliferous and saccharoidal. Abundant crinoid columnals and large megalodont bivalves. Small ribbonlike incrusting corals common, 4 to 5 cm long. Unit oolitic in part with some pisolites and algal-coated grains up to 0.4 mm in diameter.	2.4
5	Limestone and thin shales interbedded. Limestone thin-bedded and fine to medium-grained.	15.3
4	Limestone, thin to medium-bedded, light-gray calcarenite. Gastropod, bivalve, and crinoid fragments common.	22.3
3	Covered interval.	9.2
2	Limestone, silty, medium to fine-grained, weathers reddish.	9.1
1	Limestone, thin to medium-bedded, light-gray, varies from medium to coarse-grained. Some beds mottled and saccharoidal. Occasional oolite beds. Large megalodont bivalves common.	22.0

Total thickness measured: 153.5 m.

APPENDIX C: Measured Section in the Wallowa Mountains, Oregon

Eagle Creek Locality

Southern Wallowa Mountains, Oregon. Martin Bridge Formation. Section measured on the west side of Eagle Creek near the junction with Paddy Creek. NE¼, sec. 21, T. 7 S., R. 44 E.

Unit	Description	Thickness (m)
15	Limestone, recrystallized, fine to coarse-grained; thin beds alternate with thicker beds; occasional breccia and intraclast beds. Limestone coralliferous at top with colonial corals, mollusks, and echinoderm plates; small *in situ "Thecosmilia"* or spongiomorph colonies 15 to 30 cm in diameter; *Actinastraea* sp., branching *?Elysastraea profunda* and *Montlivaltia norica.* Most coral colonies are flat and platy, 30 to 60 cm long, and 5 to 8 cm thick; all corals are highly recrystallized; corals do not form framework structures within the limestone.	32.0
14	Covered interval.	75.0
13	Limestone, thick-bedded, fine to medium-grained and brecciated in part with angular, fine grained clasts; no fossils.	6.1
12	Covered interval.	40.0
11	Limestone, thin-bedded, dark, fine-grained; with abundant *Halobia* shell hash.	5.5
10	Limestone, thin to medium-bedded, fine-grained, with thin shale partings.	5.0
9	Alternating dark limestones and shales. Limestone beds 10 to 20 cm thick; medium to fine-grained; shale intervals contain *Halobia.*	24.8
8	Limestone, thin-bedded, gray beds 15 to 30 cm thick and dominantly fine-grained.	5.0
7	Limestone, argillaceous, partly covered.	4.3
6	Shale, fissile, bituminous, with occasional thin limestone beds; massive limestone bed 1 m thick at top containing abundant angular clasts up to 1 cm in diameter.	11.6
5	Limestone, thin-bedded, fine-grained, argillaceous, grades upward into bituminous, calcareous shale. Ammonite impressions and *Halobia* common. Limestone beds are fine grained and contain abundant angular clasts up to 16 cm in diameter.	8.0
4	Alternating shale and limestone beds, shale, bituminous, dark, limestone beds, 9 to 15 cm thick, fine-grained. Upper 6 m is more argillaceous with *Halobia.*	10.3
3	Covered interval.	5.5
2	Limestone, thin-bedded, dark, argillaceous; with *Halobia.*	5.0
1	Shale, fissile, thin-bedded and dark with thin limestone beds.	7.0

Total thickness measured: 244.8 m.

APPENDIX D: Measured Section at Lewiston, Idaho

Quarry on east side of Mission Creek, Lapwai Indian Reservation Nez Perce County, Idaho. NW¼, sec. 15, T. 34 N., R. 3 W. Rocks dip 50° south.

Unit	Description	Thickness (m)
4	Limestone, thick-bedded, medium-grained, partly recrystallized, coralliferous; abundant *"Thecosmilia"* branches and thin incrusting corals. Framework structure not present.	8.0
3	Limestone, reefoid, thick-bedded, fine to medium-grained; with abundant branching and platy corals forming a framework structure; much broken coral debris composed of *"Thecosmilia"* branches, platy flat *Actinastraea* fronds, 0.6 to 1.2 cm thick and 10 to 20 cm long; occasional ribbonlike incrusting corals; gastropods and bivalves common.	4.0
2	Limestone, coralliferous, medium-grained, crystalline; abundant branching corals ?*"Thecosmilia"* and minor incrusting, ribbonlike corals; gastropods and bivalves common.	6.1
1	Limestone, massive-bedded, gray; bivalves and gastropods abundant; mostly fine-grained limestone, few corals.	15.3

Total thickness measured: 33.4 m.

APPENDIX E: Measured Section at Vancouver Island, British Columbia

Section measured on south shore of Lake Cowichan across the lake from Youbou; Long. 124°13′55″, Lat. 48°51′25″; Sutton Formation; beds dip 45° northwest. Section measured at two outcrops on east and west sides of a small inlet of the lake (locality of Clapp and Shimer, 1911). (Top of section, east side of inlet.)

Unit	Description	Thickness (m)
10	Limestone, light-gray, dense and massively-bedded, medium to coarse-grained and bioclastic; fine fossil debris with traces of faint, small cross laminations at top of unit.	3.8
9	Limestone, thick-bedded, reefoid; with abundant corals. Limestone thickens and can be traced laterally into bivalve beds; branching *"Thecosmilia" dawsoni* colonies 10 to 15 cm high and 25 cm wide and branching *Thamnasteria* (30 cm wide); much broken coral debris; silicified, abundant, incrusting, matlike *Elysastraea profunda* 15 cm in diameter and thicker colonies of *E. vancouverensis; Actinastraea schafhaeutli* and other corals less common. Massive heads of branching *"Thecosmilia" suttonensis* over 1 m wide and 0.65 m high at top of unit; occasional angular volcanic clasts occur with corals. Brachiopods are occasionally associated with corals.	2.4
8	Limestone, gray, thick-bedded; with abundant molluskan shells. Fossil shell debris increases toward top where a bivalve coquina is present; silicified *Costatoria* and other bivalves abundant; rare aulacoceratid cephalopods.	3.9
7	Limestone, dark-gray, blocky, with thin shale partings; beds 15 to 20 cm thick; few fossils observed.	3.7
6	Limestone, gray, coarsely crystalline, medium-bedded; beds 30 to 90 cm thick; thin cherty beds in upper part. Few fossils observed; dark bituminous fragments (?wood) common.	8.6
5	Limestone, thick-bedded, gray, bioclastic; bivalve hash with abundant *Minetrigonia, Costatoria,* and *Myophoria;* beds at top argillaceous.	1.5
4	Interval covered by water.	40.0
3	Limestone, bioclastic, ?thick-bedded; abundant bivalve coquina with *Myophoria, Minetrigonia,* and rare incrusting corals; indet. ammonite impression.	1.0
2	Limestone, gray, thick-bedded, fine-grained, reefoid; with abundant *in situ* incrusting, branching, and platelike corals; *Elysastraea profunda* and *E. vancouverensis* abundant. Also poorly preserved branching *Astraeomorpha cuneata* and *"Thecosmilia" dawsoni;* occasional bivalves and brachiopods; approximately half of corals are branching *Thamnasteria.*	1.8
1	Limestone, gray, fine to medium-grained with dark laminations; fine fossil debris observed.	5.0

Total thickness measured: 71.7 m.

APPENDIX F: Measured Section at Iliamna Lake, Alaska

Unnamed limestone exposed on the north shore of the lake, east of Millets Point; NE¼, sec. 2, T. 5 S., R. 31 W. Thick sequence of massively bedded, dark limestone, folded and intruded, dipping steeply southwest. Section measured at first good exposure along beach.

Unit	Description	Thickness (m)
7	Limestone, highly crystalline and fractured, dark-gray; with occasional coral fragments and ?spongiomorphs. Unit intruded by volcanics. Fossils poorly preserved.	15.0
6	Limestone, fine-grained, bituminous, black; with abundant ribbonlike *Spongiomorpha* and branching *Coccophyllum.* Flat, platy colonies of *Actinastraea; "Thecosmilia," "Montlivaltia,"* and *Elysastraea* common; spiriferid brachiopods, bivalves, and branching spongiomorphs toward top. *Heterastridium* throughout.	5.2
5	Limestone, cherty, fine-grained, dark-gray, bituminous with calcite stringers; coral and spongiomorphs at top of unit; *"Thecosmilia"* common. Crinoid columnals present; gastropods rare.	2.5
4	(Volcanic dike)	
3	Limestone, fine-grained, massively bedded, black, bituminous; abundant incrusting corals *Elysastraea* and *Actinastraea* 5 to 10 cm in length; abundant, fingerlike branches of *Spongiomorpha* 5 to 10 cm long. Larger, massive, botryoidal masses of *Spongiomorpha,* 10 cm thick. Abundant thin, ribbonlike *Spongiomorpha; "Montlivaltia"* common especially at top of unit; *Heterastridium* present throughout.	7.3
2	Limestone similar to below but with abundant branching spongiomorphs and incrusting corals; lower part of unit argillaceous. *Heterastridium* present.	1.2
1	Limestone, fine-grained, massively bedded, blue-gray, minor silicified zones and stringers of chert, limestone bituminous with fetid odor when broken.	2.7

Total thickness measured: 35.5 m.

EXPLANATION OF PLATES

PLATE 1

FIGURE

1. *Actinastraea idahoensis* (Squires), ×3. Lewiston, Idaho. USNM no. 252707.
2. *A. schafhaeutli* (Winkler), ×5. Lewiston, Idaho. USNM no. 252708.
3. *A. ohmanni* (Frech), small colony showing branching growth form, ×2. Vancouver Island. KUMIP 113706.
4. *A. ohmanni* (Frech), view of another specimen, ×2. Vancouver Island. KUMIP 113707.
5. *A. ohmanni* (Frech), small fragment of a branching colony, ×2. Vancouver Island. KUMIP 113708.
6. *A. waltheri* (Frech), ×4. Pilot Mountains, Nevada. KUMIP 113675.
7. *A. juvavica* (Frech), ×1.5. Pilot Mountains, Nevada. KUMIP 113665.
8. *Astraeomorpha confusa* var. *minor* (Frech), small portion of a delicate branched form, ×3. Vancouver Island. KUMIP 113710.
9. *Actinastraea shastensis* (Smith), ×2. Pilot Mountains, Nevada. KUMIP 113670.
10. *Thamnasteria smithi* (Squires), ×4. Lewiston, Idaho. USNM no. 252709.
11. *Astraeomorpha confusa* (Winkler), ×1.5. Pilot Mountains, Nevada. KUMIP 113666.
12. *Thamnasteria rectilamellosa* (Winkler), ×1.5. Pilot Mountains, Nevada. KUMIP 113705.

PLATE 2

FIGURE

1. Polished longitudinal section through several colonies of *Thamnasteria rectilamellosa* (Winkler), ×0.4. Pilot Mountains, Nevada. KUMIP 113679.
2. *Pinacophyllum* cf. *P. parallelum* Frech, weathered in matrix, ×3. Pilot Mountains, Nevada. KUMIP 113703.
3. *Coccophyllum acanthophorum* Frech, surface of several coral-lites, ×2. Vancouver Island. KUMIP 113701.
4. *Astraeomorpha cuneata* (Squires), showing irregularly branching growth, ×0.5. Vancouver Island. KUMIP 113699.
5. Coral assemblage in growth positions with branches of *Coccophyllum acanthophorum* Frech in center, *"Thecosmilia"* common, ×1. Vancouver Island. KUMIP 113701.
6. Large solitary *"Montlivaltia" norica* Frech in growth position on an incrusting colony of *Coccophyllum acanthophorum,* ×1. Lewiston, Idaho. USNM no. 252710.
7. *Coccophyllum acanthophorum* Frech, portion of a branch, ×3. Vancouver Island. KUMIP 113701.
8. *"Montlivaltia" norica* Frech, view of calyx, ×1.5. Lewiston, Idaho. USNM no. 252711.
9. *"M." norica,* showing budded individuals, ×1. Lewiston, Idaho. USNM no. 252712.
10. *"M." norica,* same specimen as above, side view, ×1.

PLATE 3

FIGURE

1. *"Thecosmilia"* cf. *"T." fenestrata* (Reuss), specimen in matrix, ×0.8. Pilot Mountains, Nevada. KUMIP 113694.
2. *"T." suttonensis* (Clapp and Shimer), specimen illustrating nearly parallel branches with small horizontal connections between branches, ×1. Vancouver Island. KUMIP 113676.
3. Coral assemblage with numerous small branching colonies of *"Thecosmilia" dawsoni* (Clapp and Shimer) in upper left; at lower right, sheetlike incrusting *Elysastraea vancouverensis* (Clapp and Shimer), ×0.7. Vancouver Island. KUMIP 113698.
4. Transverse cross section of a colony of *"Thecosmilia" suttonensis* showing closely packed nature of corallites, ×1. Vancouver Island. KUMIP 113700.
5. Colonies of *"Thecosmilia" delicatula* (Frech) in the matrix, ×0.75. Pilot Mountains, Nevada. KUMIP 113669.
6. Coral assemblage with numerous sheetlike masses of incrusting *Elysastraea profunda* (Reuss) and other corals; terebratulid brachiopod near center, ×0.6. Vancouver Island. KUMIP 113697.
7. *Elysastraea parva* (Smith), ×2. Pilot Mountains, Nevada. KUMIP 113673.
8. *E. profunda* (Reuss), surface of coralla, ×2. Lewiston, Idaho. USNM no. 252713.

PLATE 4

FIGURE

1. *Margarastraea norica* (Frech), weathered surface, ×2. Pilot Mountains, Nevada. KUMIP 113668.
2. *M. eucystis* (Frech), weathered surface, ×1.5. Pilot Mountains, Nevada. KUMIP 113624.
3. *Elysastraea vancouverensis* (Clapp and Shimer), ×4. Vancouver Island. KUMIP 113711.
4. *Palaeastraea descussata* Reuss, surface of incrusting corallum, ×2. Pilot Mountains, Nevada. KUMIP 113689.
5. *P. descussata* Reuss, specimen exhibiting branching growth, ×1. Gravina Island, Alaska. KUMIP 113712.
6. Branching hydrozoan resembling *Tubulitrypa maculata* Flügel, ×2. Lewiston, Idaho. USGS Mesozoic coll. no. 17424.
7. Numerous branches of *Spongiomorpha ramosa* Frech incrusted by the coral *Coccophyllum,* ×1. Iliamna Lake, Alaska. KUMIP 113649.
8. Hydrozoan resembling *Tubulitrypa maculata* Flügel, ×2. Lewiston, Idaho. USGS Mesozoic coll. no. 17424.
9. Hydrozoan resembling *Zlambachella alpina* Flügel, ×2. Lewiston, Idaho. USGS Mesozoic coll. no. 17424.
10. Massive nodular specimen of *Spongiomorpha* sp. showing lamellate growth, ×0.4. Black Marble Quarry, Oregon. KUMIP 113677.
11. *Spongiomorpha ramosa* (Frech), showing polished cross section of part of a branch, ×2. Iliamna, Alaska. KUMIP 113651.

PLATE 5

FIGURE

1. *Spongiomorpha gibbosa* Frech, longitudinal polished section of a cylindrical specimen, ×2. Pilot Mountains, Nevada. KUMIP 113686.
2. *S. gibbosa* Frech, transverse cross section of specimen in Figure 1, ×2.
3. *S. gibbosa* Frech, weathered cylindrical specimen, ×1. Pilot Mountains, Nevada. KUMIP 113690.
4. *S. gibbosa* Frech, detailed view of weathered surface, ×5. Pilot Mountains, Nevada. KUMIP 113690.
5. *Spongiomorpha* sp., polished longitudinal section of a specimen with numerous borings in the skeleton, ×2. Pilot Mountains, Nevada. KUMIP 113723.
6. *Heptastylis* cf. *H. stromatoporoides* Frech, naturally weathered longitudinal section showing numerous convex individuals, ×0.6. Pilot Mountains, Nevada. KUMIP 113672.

7. *Spongiomorpha* cf. *S.* sp. A Flügel and Sy, note irregularly incrusting growth, ×0.6. Iliamna Lake, Alaska. KUMIP 113650.

PLATE 6

FIGURE

1. *Spongiomorpha tenuis* Smith, cross sectional view of a portion of polished surface, ×2. Pilot Mountains, Nevada. KUMIP 113704.
2. *S. tenuis* Smith, numerous masses of elongate, subparallel branches, ×1.5. Eagle Creek, Southern Wallowa Mountains, Oregon. KUMIP 113662.
3. *Spongiomorpha* sp., longitudinal cross section showing numerous incrusting growth forms, ×1.5. Black Marble Quarry, Oregon. KUMIP 113660.
4. *S. ramosa* Frech, unoriented section through large branching specimen showing details of coenosteum, ×3. Iliamna Lake, Alaska. KUMIP 113717.
5. *S. californica* Smith, longitudinal section of a massive, partly silicified specimen showing the lamellae and pillar elements, ×1.5. Gravina Island, Alaska. KUMIP 113713.
6. *Heptastylis* sp., longitudinal section showing incrusting growth, ×1.5. Black Marble Quarry, Oregon. KUMIP 113716.
7. *Spongiomorpha acyclica* Frech, longitudinal section through globular colony showing laminar growth, ×2. Iliamna Lake, Alaska. KUMIP 113653.
8. *Heterastridium conglobatum* Reuss, longitudinal cross section through nearly spherical coenosteum showing finely perforate interior, ×1.5. Iliamna Lake, Alaska. KUMIP 113714.
9. *H. conglobatum* Reuss, transverse section of a partly recrystallized specimen of ellipsoidal outline displaying concentric laminations, ×1.5. Iliamna Lake, Alaska. KUMIP 113654.

PLATE 7

FIGURE

1. *Ascosymplegma expansum* Seilacher, specimen in matrix showing details of perforated exterior wall and chambered interior, ×1. Pilot Mountains, Nevada. KUMIP 113667.
2. *A. expansum,* specimen in matrix which has grown over itself, ×0.3. Pilot Mountains, Nevada. KUMIP 113685.
3. Polished longitudinal cross section of *A. expansum* showing incrustation over spiriferid brachiopods, ×1. Pilot Mountains, Nevada. KUMIP 113671.
4. *Polytholosia cylindrica* Seilacher, transverse section through sponge, interior almost completely filled with fine-grained micrite. Note spar-filled void at top; this geopetal structure indicates position in which sponge rested after burial, ×1.5. Pilot Mountains, Nevada. KUMIP 113692.
5. *P. cylindrica,* complete specimen showing faint segmentation of exterior and perforate walls, ×0.8. Pilot Mountains, Nevada. KUMIP 113695.
6. Natural transverse cross section through *P. cylindrica* revealing the vesicular structure of interior, ×1. Pilot Mountains, Nevada. KUMIP 113691.
7. Another natural transverse cross section of *P. cylindrica* at a different position showing elliptical outline, ×1. Pilot Mountains, Nevada. KUMIP 113691.
8. *P. cylindrica,* polished longitudinal section showing internal partitions and fine-grained micrite filling interior cavity, ×1.5. Pilot Mountains, Nevada. KUMIP 113719.

PLATE 8

FIGURE

1. Calcisponge *Ascosymplegma* in black limestone matrix, ×0.5. Black Marble Quarry, Oregon. KUMIP 113684.
2. *Waagenella* cf. *W. timorica* (Vinassa), weathered surface showing the chambers in this sponge, ×1.5. Black Marble Quarry, Oregon. KUMIP 113683.
3. Side view of pharetronid sponge *?Peronidella* sp. with three chambers, ×2. Lewiston, Idaho. USGS Mesozoic coll. no. 17424.
4. *Thamnastocoelia* sp., transverse view of a single chamber showing osculum, ×5. Lewiston, Idaho. USGS Mesozoic coll. no. 17424.
5. Rhynchonellid brachiopod showing strong plications, ×1.5. Pilot Mountains, Nevada. KUMIP 113687.
6. Lateral view of specimen in Figure 5, ×1.5.
7. *"Terebratula" suttonensis* Clapp and Shimer, showing smooth shell with growth lines, ×2. Vancouver Island. KUMIP 113647.
8. Terebratulid brachiopod showing relatively smooth shell and small foramen, ×1.5. Pilot Mountains, Nevada. KUMIP 113688.
9. Side view of specimen in Figure 8, ×1.5.
10. *Zugmayerella uncinata* (Schafhaeutl), side view showing strong plications, ×1.5. Pilot Mountains, Nevada. KUMIP 113696.
11. *Z. uncinata,* side view of a specimen showing high pedical valve and curved beak, ×1.5. Pilot Mountains, Nevada. KUMIP 113718.
12. *Z. uncinata,* showing large high interarea and delthyrium, ×1.5. Pilot Mountains, Nevada. KUMIP 113696.
13. Polished slab showing *Zugmayerella* in the matrix with incrusting sponge above, ×1. Pilot Mountains, Nevada. KUMIP 113679.
14. Side view of indeterminate spinose bivalve in the matrix, ×1. Black Marble Quarry, Oregon. KUMIP 113720.
15. *Minetrigonia suttonensis* (Clapp and Shimer), ×3. Vancouver Island. KUMIP 113661.

PLATE 9

FIGURE

1. *Trichites* sp., interior view of one valve showing the undulations around the shell margin and deep adductor scar, ×0.5. Pilot Mountains, Nevada. KUMIP 113678.
2. *Trigonia* (*Kumatrigonia*) sp., view of exterior of a partially broken right valve, ×1.5. Lewiston, Idaho. USGS Mesozoic coll. no. 17424.
3. Interior view of specimen in Figure 2, ×1.5.
4. Myophorid bivalve, exterior view of left valve, ×1.5. Lewiston, Idaho. USGS Mesozoic coll. no. 17424.
5. Interior of specimen in Figure 4, ×1.5.
6. Silicified bivalve coquina from bivalve bed at Vancouver Island; most specimens are *Minetrigonia* and *Costatoria,* ×1. KUMIP 113662.
7. *Purpurina gravinaensis* Smith, ×1. Gravina Island, Alaska. KUMIP 135248.
8. *Prolocula bassetti* Smith, ×1.5. Gravina Island, Alaska. KUMIP 135247.
9. Longitudinal section of a partially recrystallized coral skeleton that contains numerous small cavities produced by boring bivalves; large borehole at top is still occupied by an unidentified bivalve, ×3. Pilot Mountains, Nevada. KUMIP 113702.
10. Polished slab showing crinoidal and molluscan debris, ×1.5. Pilot Mountains, Nevada. KUMIP 113724.

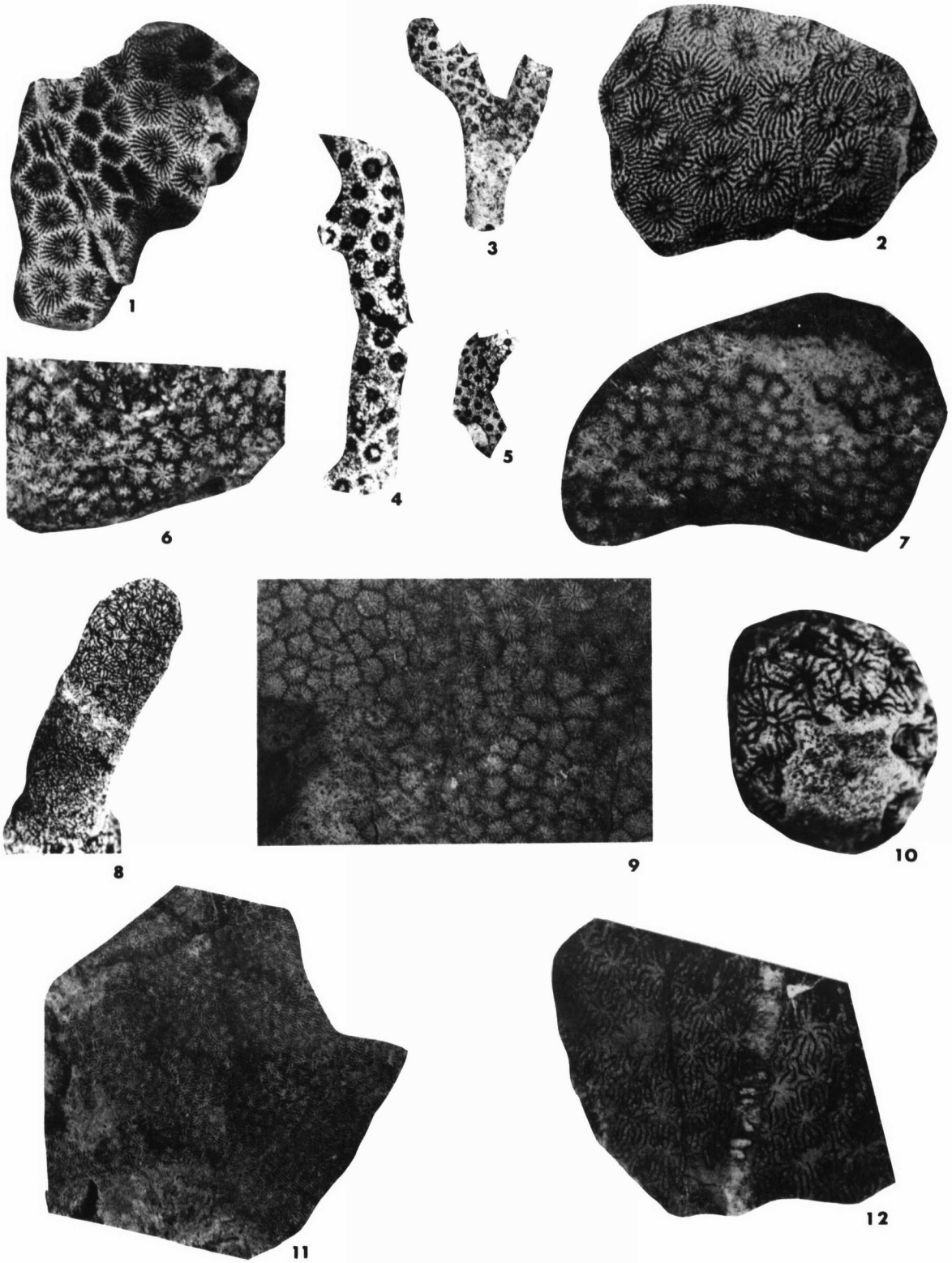
PLATE 10

FIGURE

1. Mollusk packstone from beds overlying the coral buildups; note numerous cross sections of bivalves, ×1.5. Vancouver

Island, British Columbia. KUMIP 113722.

2. Coral framestone showing transverse view of branching *Thamnasteria* colony; many of the small angular constituents are volcanic rock fragments, ×1.5. Vancouver Island, British Columbia. KUMIP 113709.
3. Branching *Thamnasteria,* sponges, and other fossil debris in a black, fine-grained matrix; cross sections of several calcisponges at right, ×1.5. Black Marble Quarry, Oregon. KUMIP 113721.
4. Recrystallized incrusting *Elysastraea* with bivalve debris in dark, fine-grained limestone, ×1.5. Iliamna Lake, Alaska. KUMIP 113715.
5. Partially recrystallized coral and spongiomorph debris (wackestone), cross section of *"Thecosmilia"* in upper left, incrusting *Spongiomorpha* are common, ×1. Iliamna Lake, Alaska. KUMIP 113680.
6. Mollusk-coral packstone with abundant bivalve shells, calcareous red alga *Gymnocodium* in upper center, ×3. Iliamna Lake, Alaska. KUMIP 113681.
7. Part of a branching thallus of *Gymnocodium* in dark fine-grained limestone, ×2. Iliamna Lake, Alaska. KUMIP 113680.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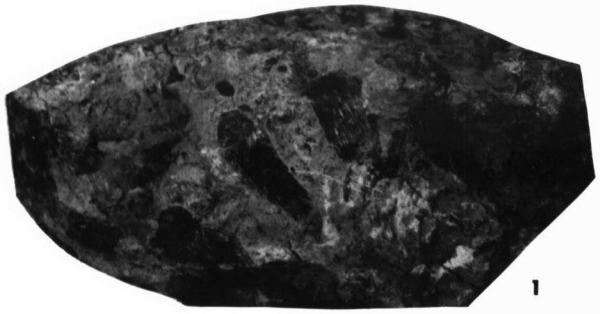
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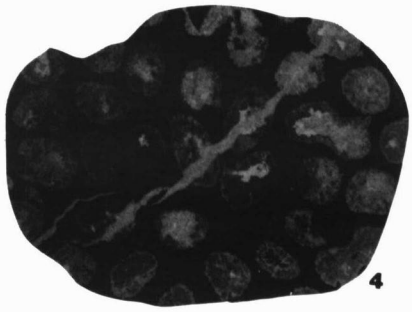
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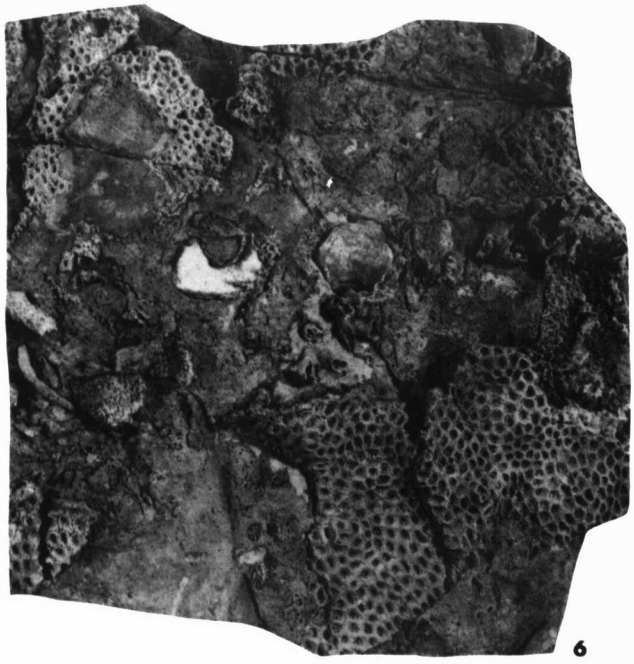
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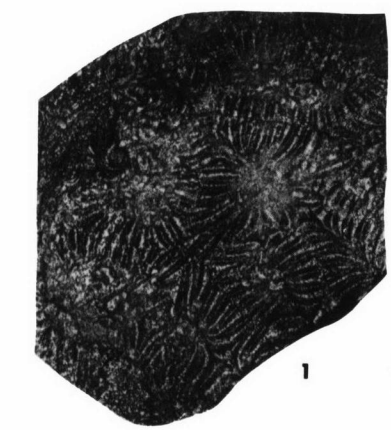
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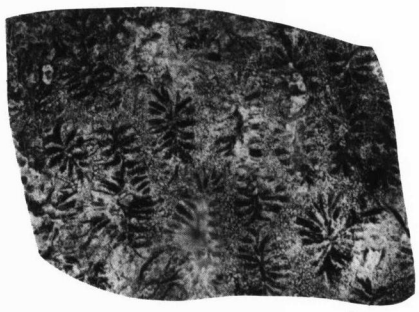
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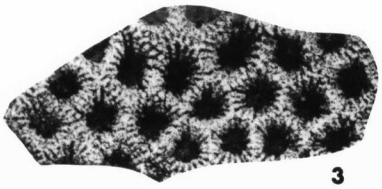
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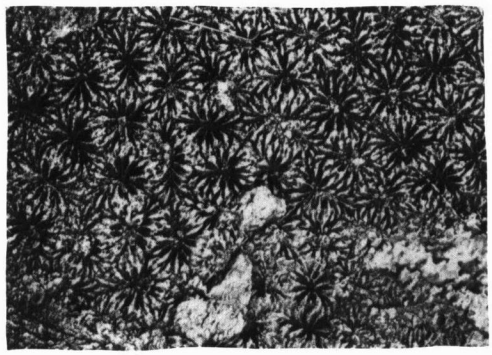
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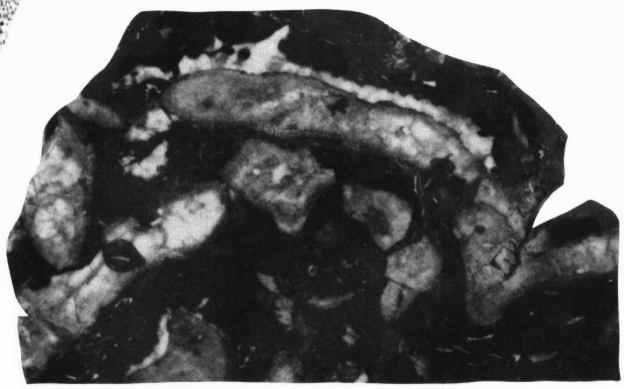
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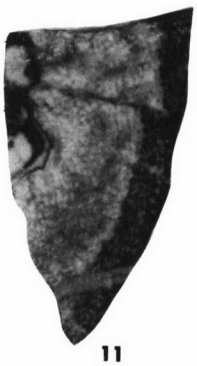
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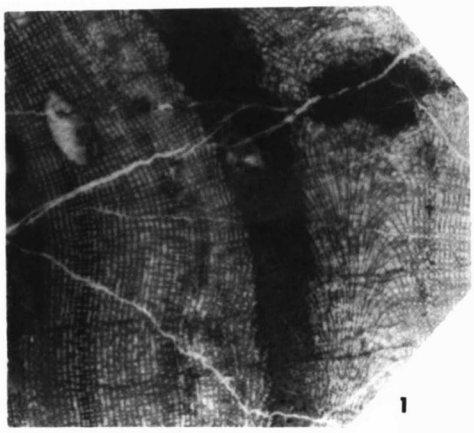

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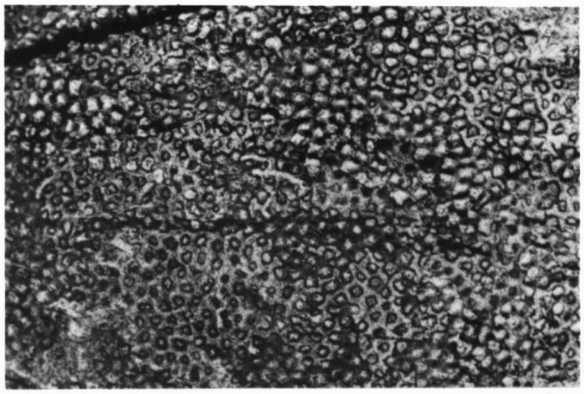

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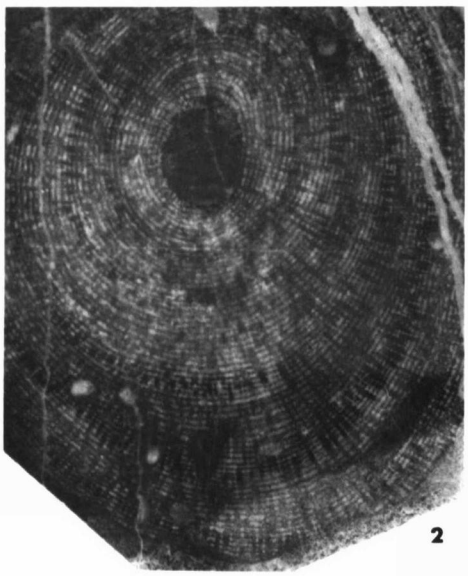

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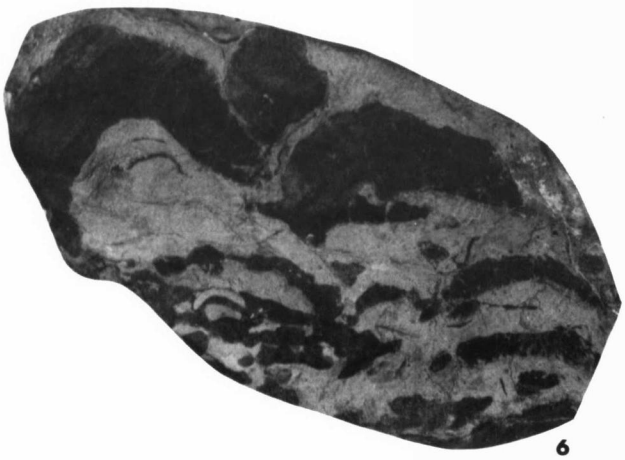

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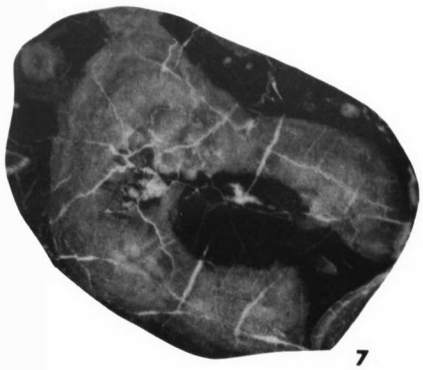

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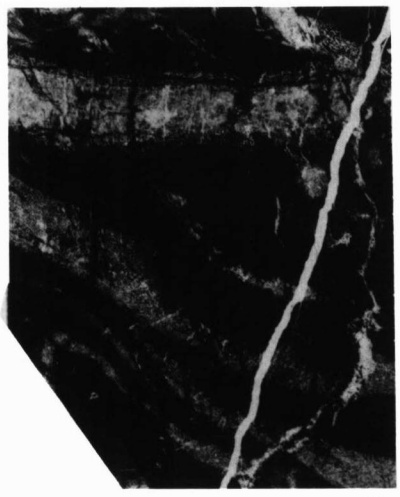

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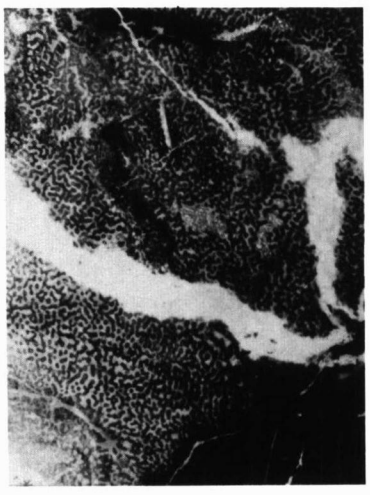

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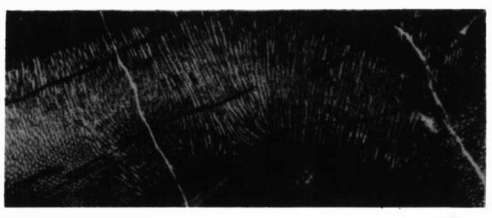

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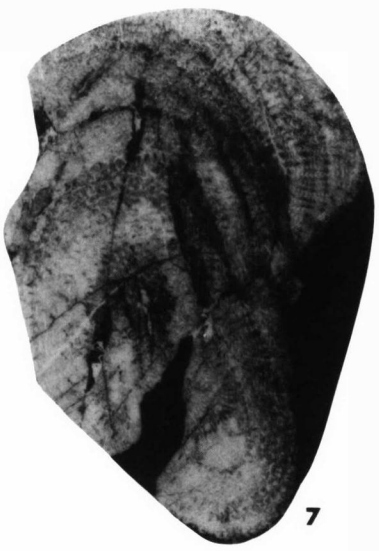

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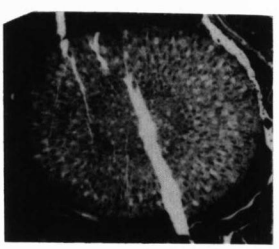

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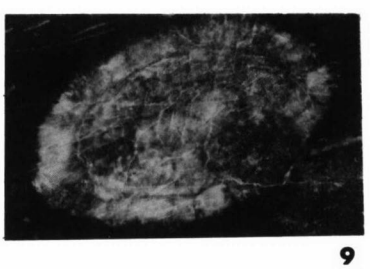

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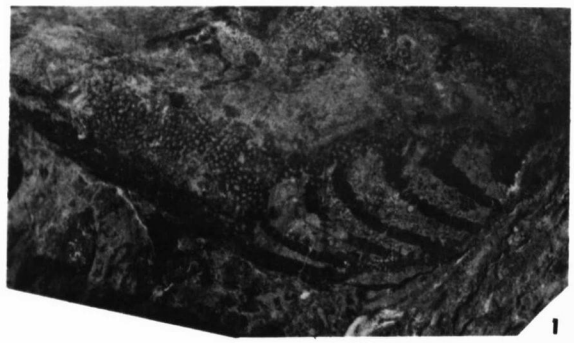
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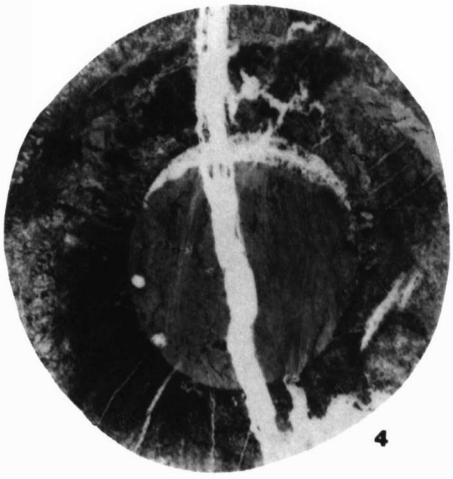
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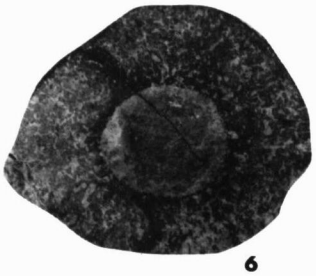
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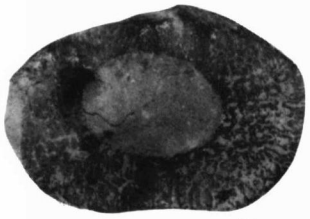
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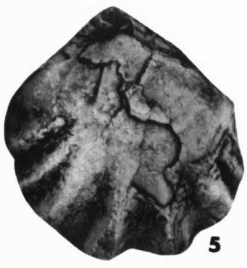
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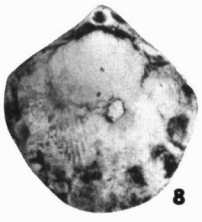
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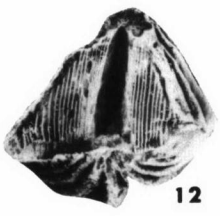
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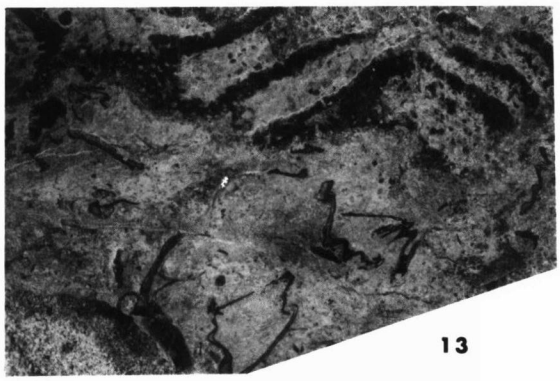
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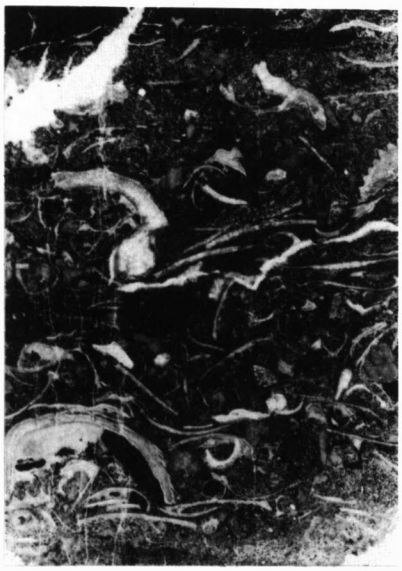

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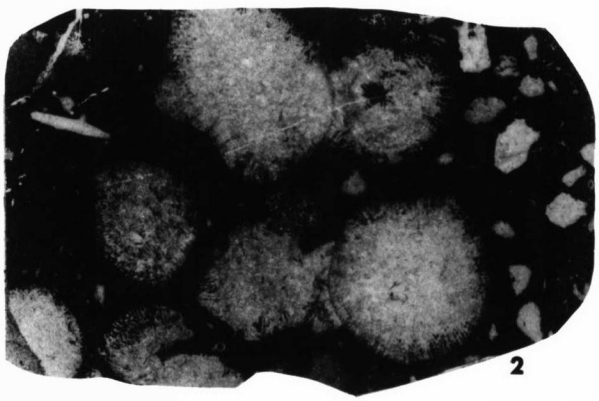

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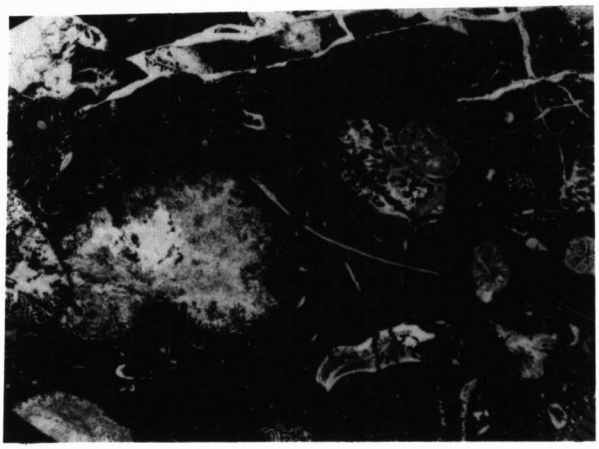

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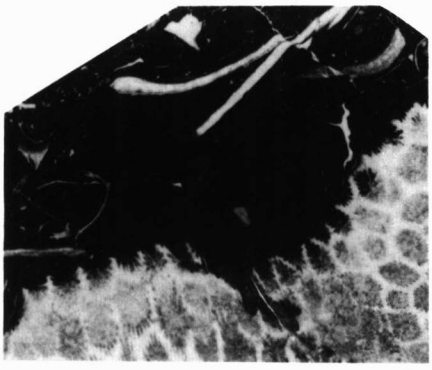

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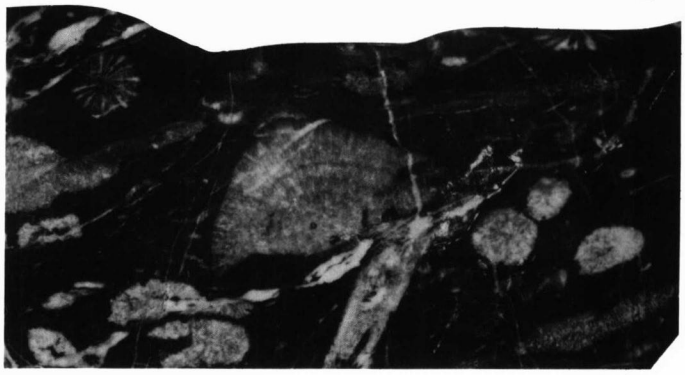

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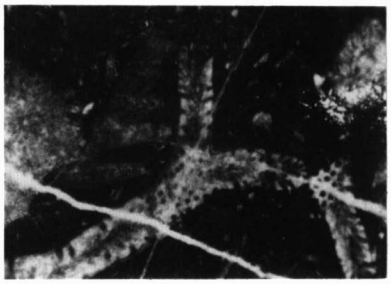

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